THE MAGAZINE THAT FEEDS MINDS

HOW IT WORKS™

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RACING CARS

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ISSUE 059

ISSUE 59

WELCOME

The magazine that feeds minds!

Page 42
Explore the planet's most supersized telescopes and discover what cosmic wonders they have uncovered...

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This year, Formula 1 has seen the biggest shakeup in regulations since the sport began, calling for a total evolution of the engineering under the hood. From hybrid engines that convert braking and exhaust heat into power, to safer and more streamlined bodies, 2014's F1 cars have really stepped up a gear. And that's no mere figure of speech, as they've gone from seven to eight gears too.

In fact, racing cars in general have seen a massive overhaul in the technology stakes. Engineers are making the stars of the show not just faster and more powerful, but also greener, safer and lighter than ever. Even better for us non-racing types, some of that amazing engineering is trickling down to road cars too. The feature revs up on page 14.

In this issue we also plunge into Earth's oceans to explore the most amazing wonders under the waves, from smouldering volcanoes to global currents and our planet's diverse marine life from tiny plankton to massive whales.

Enjoy the issue.

Adam

Adam Millward
Deputy Editor

Meet the team…

Marcus
Senior Designer
We regularly feature breath-taking intergalactic images in **How It Works** so it was amazing to meet the telescopes behind them.

Erlingur
Production Editor
As a fan of things that go 'vroom!' past other things that go 'vroom!' I liked the racecar tech feature, easily our 'vroom'-iest one this month.

Jamie
Staff Writer
I've long been interested in the wonders of forensic science, so it's great to see how far it's advanced since the days of *Inspector Morse*.

Jackie
Research Editor
We've seen them in films like *Star Wars* and *Minority Report*, but holograms are far from sci-fi. See how they work on page 64.

Helen
Senior Art Editor
As a frequent flyer on planes, I found it interesting to learn where these winged wonders end up when they reach retirement age on page 22.

Jack
Staff Writer
Humanity still hasn't fully conquered the oceans. Learn everything you need to know about the deep blue yonder in our comprehensive feature.

What's in store…

The huge amount of information in each issue of How It Works is organised into these key sections:

Science
Uncover the world's most amazing physics, chemistry and biology

Technology
Discover the inner workings of cool gadgets and engineering marvels

Transport
Everything from the fastest cars to the most advanced aircraft

Space
Learn about all things cosmic in the section that's truly out of this world

Environment
Explore the amazing natural wonders to be found on planet Earth

History
Step back in time and find out how things used to work in the past

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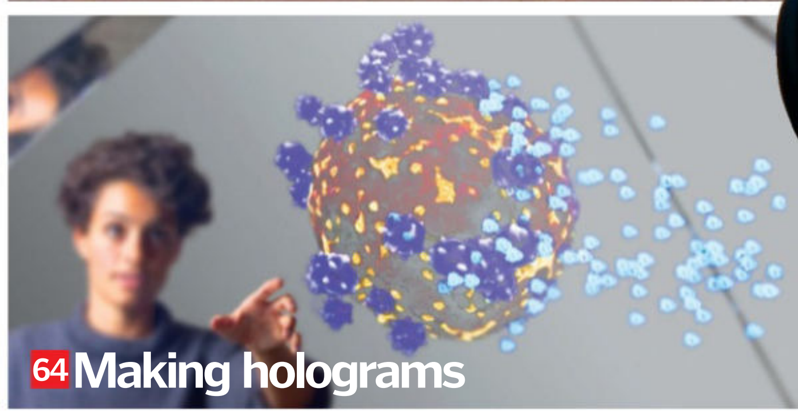

64 Making holograms

Meet the experts…

Laura Mears
Holograms
In this issue, Laura gets hands-on with lasers and lenses to reveal how the latest advances in holography are making these fascinating light projections more realistic than ever before.

Rob Jones
Cotton mills
This issue Rob travels all the way back to the Industrial Revolution to take us on a tour around a cotton mill – a factory which came to epitomise the shift to the new mechanised era.

Giles Sparrow
Mega telescopes
Giles introduces the Earth-based giants of the astronomical world, highlighting their discoveries and how they're helping us unravel the mysteries of the cosmos.

Lee Sibley
Cargo ports
Lee discovers why these massive gateways between land and sea play such a pivotal role in international trade and how they bring together a wide variety of transport.

Ella Carter
Amazing oceans
Marine biologist Ella takes us on an odyssey through Earth's briny depths, explaining how currents work, the role oceans play in climate and the incredible geology hidden in the deep.

Why is chickenpox so contagious? Find out on page 59

REGULARS

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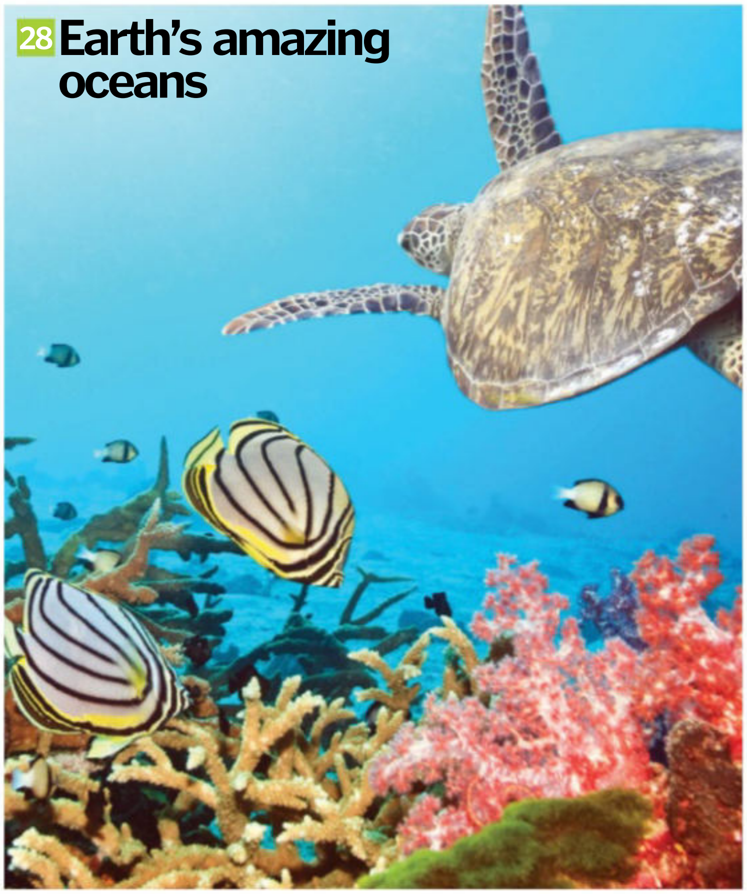
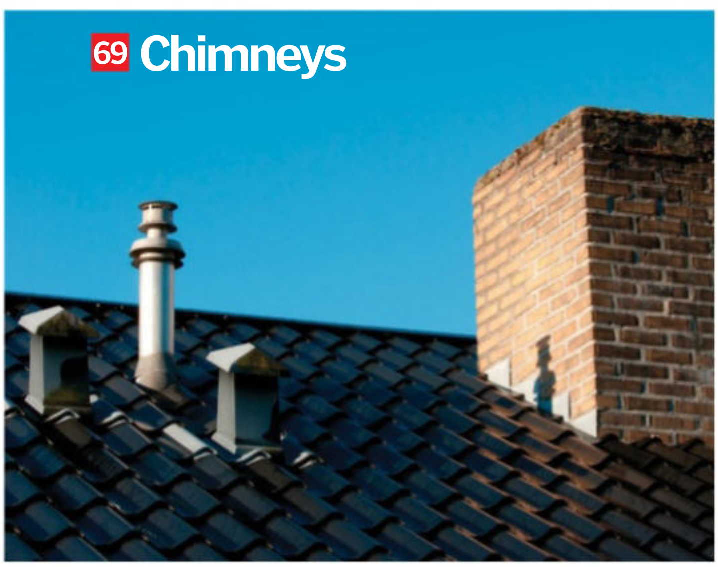
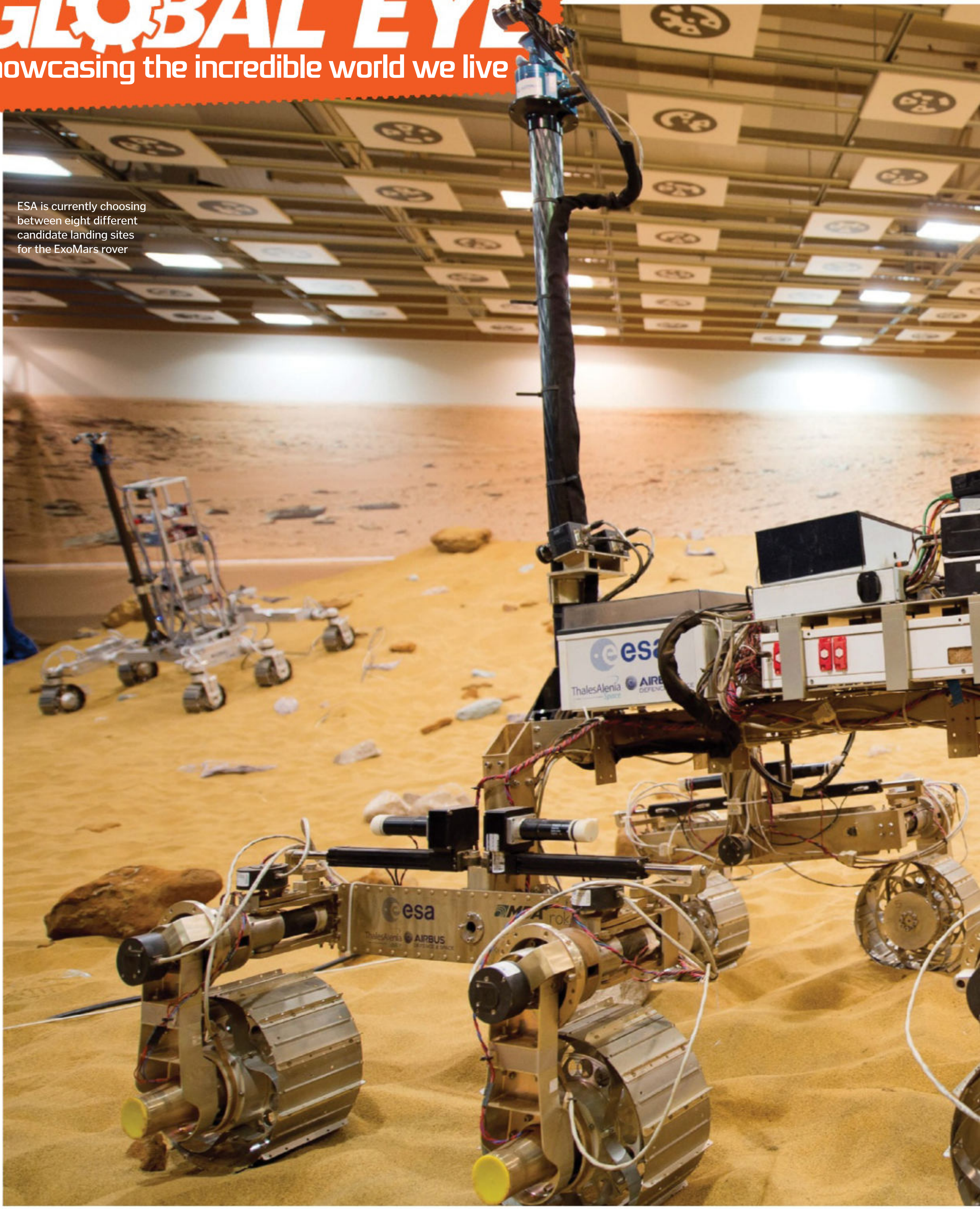






ESA is currently choosing between eight different candidate landing sites for the ExoMars rover

Humans on Mars

New rover-testing facility brings a little of the Red Planet down to Earth

At first glance, you might think that here we have the first person to venture onto Mars's surface...

But not quite. These pictures are of the ExoMars Rover and were taken in the 'Mars Yard' in Stevenage, UK. This British-built vehicle represents the next generation of explorers for the Red Planet and is part of the Airbus Defence and Space Group.

The Yard is the perfect testing ground for vehicles heading to Mars. It is made up of 300 tons of sand and rocks, aiming to simulate the uneven Martian surface. The launch of the ExoMars is planned for 2018 and it's hoped it will be able to traverse 70 metres (230 feet) of Martian landscape per day independently.

Towers of tomorrow

Skyscrapers of the future will combine tech and nature

525 designs were sent to *eVolo* architecture magazine for its 2014 skyscraper competition ranging from traditional tower blocks with a twist to outlandish mushroom-like structures. The constructions were judged on innovative use of materials, aesthetics and technology. The theme was primarily centred around harvesting energy with examples including a desert tower made of sand (right), a building with a bamboo exoskeleton and a vertical train station (below). Other concepts portrayed cities in the sky and one design even used CO_2 pollution as its building blocks.

X-rays reveal secrets of prehistoric life

New technology lets us see fossils in unprecedented detail

Feeding trails in a fossilised leaf discovered in Colorado, USA, are believed to be from an ancient caterpillar that lived some 50 million years ago. Palaeontologists exposed the leaf to X-rays in a synchrotron to capture the detail.

These rays, which are millions of times brighter than the Sun, revealed the atomic structure of the leaf and found it has very similar properties to its modern-day equivalents in terms of its levels of copper, zinc and nickel. Despite their intensity, the rays are designed to leave the samples they scan intact, making them perfect for studying fragile fossils.

Copper has been attributed with the excellent condition of the leaf as the metal works in a similar way to wood preservative.

Other famous fossil finds

Key fossils and when they were unearthed

Megalosaurus (1676)
Dug up in the UK, this was the first-ever dinosaur fossil recorded, in the 17th century.

Woolly mammoth (1796)
French scientist Georges Cuvier found the original fossils and was the first to claim they were a separate species from the elephant.

Sabre-tooth tiger (1842)
More correctly called a 'sabre-toothed cat', it was originally unearthed by Danish naturalist Peter Wilhelm Lund.

Archaeopteryx (1861)
One of the most recognisable fossils, this animal was part dinosaur, part bird and seen as a key transitional species.

Velociraptor (1924)
Like the equally famous T-rex, the first Velociraptor was found in Mongolia in the early-20th century.

Reproduced with permission of the Royal Society of Chemistry from Nicholas Paul Edwards, Phillip Lars Manning, et al

Taking science to the streets

Tim Shaw, host of hit National Geographic science show None Of The Above, talks to us about his driving passion: making science cool


In *None Of The Above*, Shaw and co blow up a coffee creamer, among many other things


Using the right methods, it's possible to make ice cream with a fire extinguisher!

What first got you interested in science?
I was sent for a dyslexia test when I was about 12 or 13 because my parents kept getting letters saying that I was easily distracted or not concentrating. I went for the test and the guy doing it said I was super quick in engineering and creativity. Apparently I challenged the guy at one point and beat him. I didn't even know I was doing it. Because of that, my parents bought me an old VW Beetle engine for about £20 ($33) and told me to go and have fun with it. It didn't matter if I broke it, fixed it or whatever.

Did your teachers at school have much of an impact in your chosen career?
When I was at school, I noticed that your science teacher has a massive effect on whether you go on to become a scientist or do something technical. If your teacher can demonstrate something interesting and cool, then that's great. Unfortunately, mine didn't, but I took what they were teaching and did my own experiments. I blew things up, set fire to things and made it exciting. All kids like to see things burning. If you stand at the front of a classroom and just explain things, no one will be interested.

How are you trying to get people interested in science in shows like *None Of The Above*?
Basically what the show was all about was communicating to the viewers that it's okay to be interested in science. You see certain people on the screen and you think that they would have no interest in science, but then as soon as you see them getting excited, suddenly it's cool. Street science is the perfect way to do this. If you are watching a comedian and no one else laughs, there aren't many people who would burst out laughing, but if everyone else laughs, you're more inclined to laugh. So if I'm doing an experiment on the show and the people I'm doing it with say it's cool, the viewer will be more likely to agree.

So are you saying that science is inherently exciting, if people just give it a chance?
Absolutely. What I'm all about is igniting the passion that's all around us. To my mind, science is much better than magic. TV has an obsession with magic at the moment, but magic is only sleight of hand. Learning about the incredible world of science will teach you something useful and could start you on a career that earns you a hundred grand a year for the rest of your life. That won't happen if you watch some magician hide some cards up his sleeve.

But can science really compete with the 'wow' factor of magic?
We try to include a couple of stunts you can do at home. For instance, if you put a ruler on the edge of a table, place a newspaper over the top and hit the ruler, the ruler breaks in half. Awesome things like that should encourage people to be interested in science. Did you know if you bump a wine bottle protected by newspaper against a wall you can pop its cork? The process is called cavitation, but who cares what it's called? Just seeing it happen, you can't help but say, 'Wow.' You can make ice cream out of a fire extinguisher. I defy anyone *not* to find that interesting. I did my degree in broadcasting as I never thought I'd get a girlfriend doing mechanical engineering, which was wrong. It's stupid to think a girl wouldn't be interested in a guy who can make ice cream from a fire extinguisher!

So why is science often seen as something boring or confusing?
I have a problem with some engineers who use other people's findings, mash them together and don't create or design anything themselves. They tell us, "Pythagoras said this, Einstein said that." Well, where are the new Pythagorases? Where are the new Einsteins? Engineers use long, technical phrases that terrify kids from entering that world. You can lose someone in just one word. If I say something happens because of gravity, it doesn't matter if you forget that word as long as you roughly know what it means. What we need to do is spark people's creativity. If you hold a bike wheel on one side using just one finger and spin it, the wheel will stay on your finger due to a gyroscopic effect. Scientists will try to explain this using terminology you would only understand if you're in the third year of a science degree, but what about the other 99 per cent?

What's your message to that 99 per cent?
Do something. Don't just sit there using your opposable thumbs on your mobile or tablet. I heard the other day that our arms are getting shorter because we don't need them any more. Celebrate your arms, use your arms, go off and do stuff, make stuff, take things to pieces and don't be scared. Open the bonnet on a car and take off the plastic shrouding and you've got a normal internal combustion engine – the same that's been powering stuff for 100 years.

The thing is not to be scared. We're here to learn. We're born with no skills but those that will let us live and breathe. Then we go through life picking up skills and learning things. Why not get stuck in and just explore? Science is super-cool and we should celebrate that.

Tim is recording another series of *None Of The Above* for the National Geographic Channel now. Check out www.howitworksdaily.com for videos of some of the amazing experiments discussed by Tim here.

10 COOL THINGS WE LEARNED THIS MONTH

New eBikes have invisible engines

By scaling down the motor so it fits inside the wheel hub, an innovative electric bike is redefining two-wheeled transport. As well as being greener than a traditional fuel-powered motorbike, a new storage space (420 x 360 x 220 millimetres/16.5 x 14.2 x 8.7 inches) has been created on the FEDDZ scooter to hold anything from your rucksack to a stack of pizza boxes. There's even a USB connection to power up your devices on the go.

Asteroids can have rings too

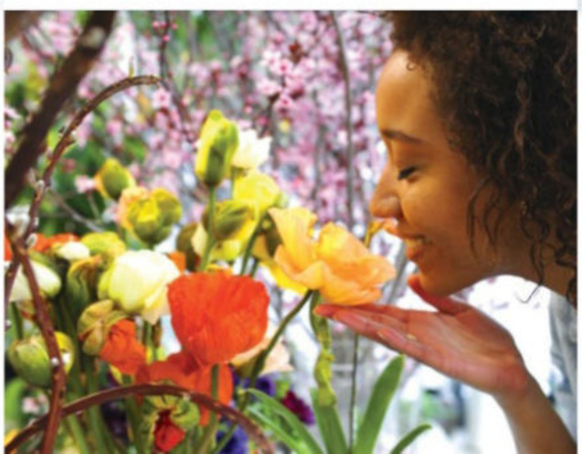
Until now the only confirmed ring systems in space have been around planets – Jupiter, Saturn, Uranus and Neptune. But thanks to astronomers in Brazil, we now know that smaller bodies can also host rings. Chariklo is a centaur asteroid 250 kilometres (155 miles) across in the outer Solar System, and the orbiting debris was spotted as it transited in front of a star. The system is made up of two narrow rings, separated by nine kilometres (5.6 miles), and is thought to be the remnant of a mighty collision. Chariklo may even host its own small moon, but this has so far evaded detection.

Cutlery can add more flavour to our food

Until now, cutlery has been a means to an end to get food from A to B – from the plate to our mouths – but that's about to change. Aromafork, made by Canadian innovator MOLECULE-R Flavors, features a capsule under the handle that houses a piece of absorbent paper. Prior to your meal, this paper can be soaked in over 20 different essences, from vanilla to wasabi, bringing a new flavour dimension to every mouthful – proving we taste as much with our noses as we do with our tongues.

Noses outsense our eyes

It's long been believed that the average human hooter can distinguish in the region of 10,000 different smells, but new research suggests our noses are far more discerning than that. Cocktails of ten, 20 or 30 molecules were mixed from 128 different scents, like citrus and grass. Participants got three vials: two containing the same cocktail and the third with a mystery odour, and then asked to identify the latter. The instances of correct identification were extrapolated to account for all possible combinations to arrive at a conservative figure of 1 trillion scents our noses can detect. This exceeds the number of colours our eyes can perceive (10 million), though we still fall short of the average dog, which can smell two to three times better than us.

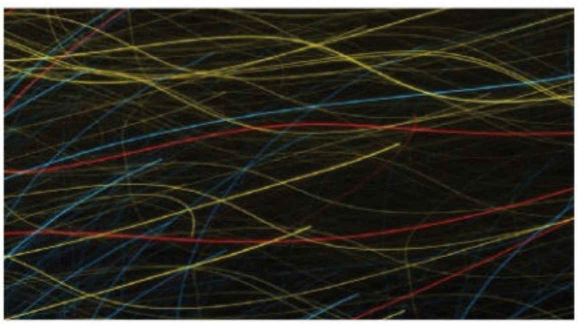


Cowboys use physics to perform rope tricks

According to a French physicist, the secret to 'trick roping' like a rodeo pro is basic maths. Dr Pierre-Thomas Brun, from EPFL in Switzerland, asserts he has mastered one of the simpler rope tricks used by cowboys, known as the 'flat loop', by applying mathematical equations gleaned from other elastic materials like hair and textiles. Brun suggests the key is to use 70 per cent of the rope in the loop, move your hands at a low frequency and to roll the rope between your finger and thumb on each turn.

Saturn's top moon is making waves

Astronomers have spotted what they think are the first extraterrestrial waves ever seen, on Saturn's largest satellite, Titan. But these waves are very different from what we're used to seeing at the beach here on Earth. For one thing, the liquid isn't water at all, but vast lakes of liquefied hydrocarbons like methane, mostly found around the moon's north pole, while what looks like solid rock is largely ice. Studying images captured by the Cassini space probe where sunlight reflected off the moon, scientists detected features consistent with waves, though the ripples only appear to be around two centimetres (0.8 inches) tall. These could be about to get a lot bigger, though, as wind speeds are on the rise with the changing seasons, potentially even leading to storm surges.

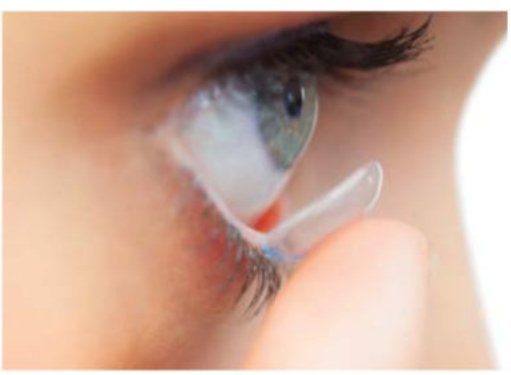


Hubble is an artist

It might look like an abstract drawing you'd see hanging in an art gallery, but this shot was captured by the Hubble Space Telescope. Hubble uses a Fine Guidance System, comprising a series of gyroscopes to sense its position and a set of reaction wheels to alter its attitude. To allow for gyroscopic drift, another part of the system focuses on a fixed point in space, known as a 'guide star'. Here, Hubble may have accidentally selected a 'bad guide star', like a binary system, confusing the tracking system, resulting in this spaghetti-like tangle of multicoloured light streaks.

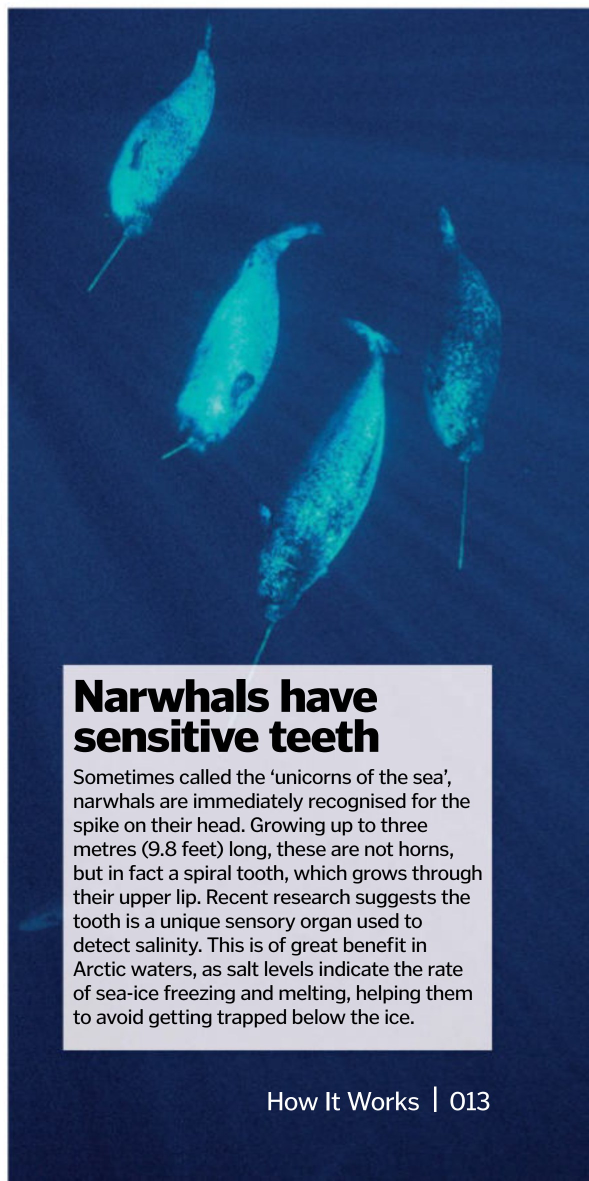
Moss can survive 1,500 years on ice

Some plants give up the ghost at the first hint of a frosty night, but others are made of far sterner stuff. In fact, moss taken from Antarctica's permafrost has recently been reanimated after an estimated 1,530 years in the deep freeze. Samples were collected from banks of moss that build up over the short summers before being placed in an incubator at 17 degrees Celsius (63 degrees Fahrenheit). After three weeks, new shoots had appeared, opening up possibilities of cryogenically freezing other multicellular organisms.



Contact lenses could help us see in the dark

Sandwiching a layer of superthin graphene into a contact lens might be the future of night-vision goggles, according to scientists at the University of Michigan. While the incredible material, comprised of a single layer of carbon atoms in a honeycomb structure, is renowned for its strength, another quality makes graphene suited to seeing in the dark. Whenever a photon in any electromagnetic wavelength – from ultraviolet to infrared – strikes graphene, a number of electrons on its surface are agitated, generating an electric signal. These signals could be processed and converted into images, providing a view of what lies ahead, even when it's pitch black.



Narwhals have sensitive teeth

Sometimes called the 'unicorns of the sea', narwhals are immediately recognised for the spike on their head. Growing up to three metres (9.8 feet) long, these are not horns, but in fact a spiral tooth, which grows through their upper lip. Recent research suggests the tooth is a unique sensory organ used to detect salinity. This is of great benefit in Arctic waters, as salt levels indicate the rate of sea-ice freezing and melting, helping them to avoid getting trapped below the ice.

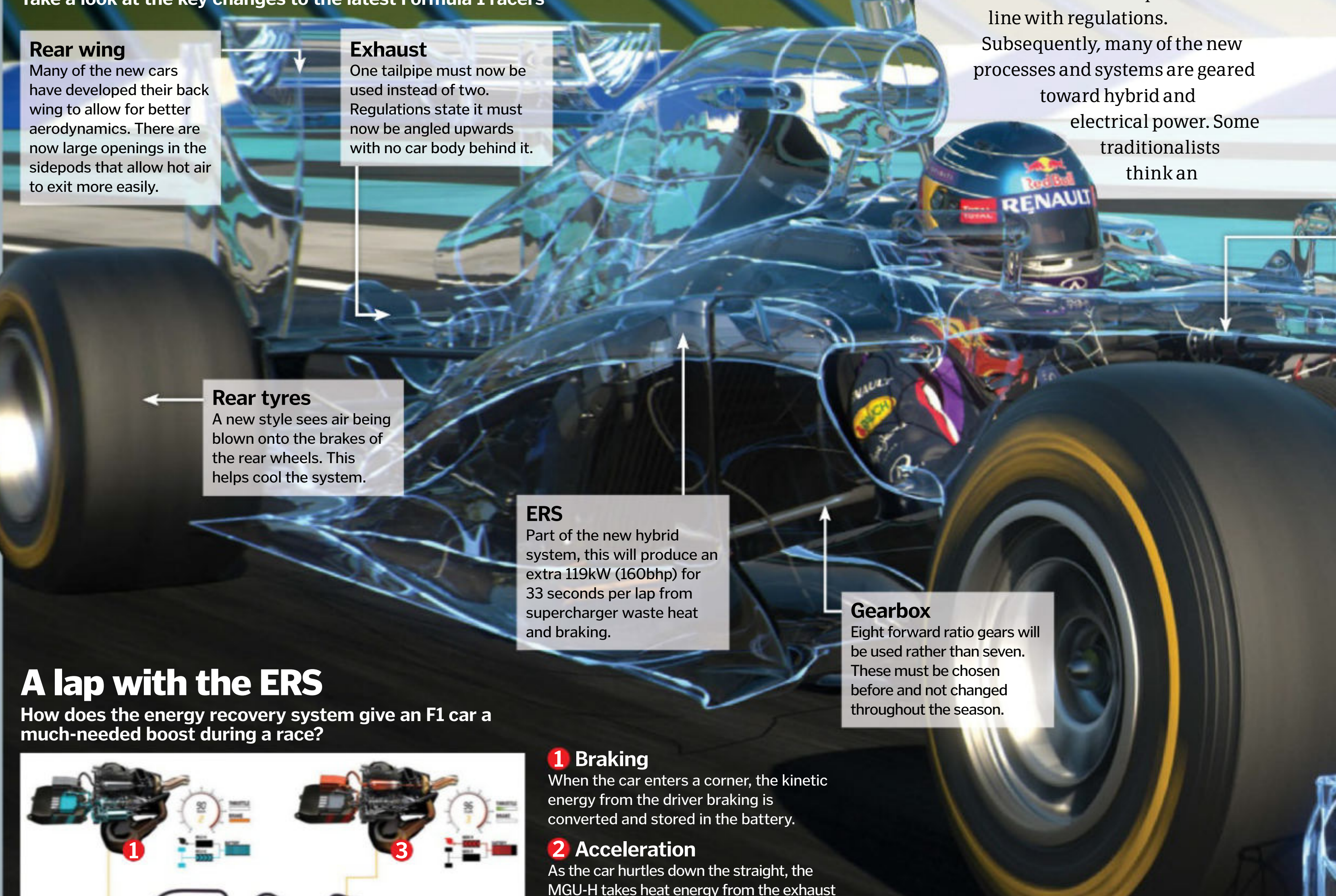
Racing cars

From hybrid engines to new designs, today's racing engineering is stepping up a gear…

All through the racing spectrum, vehicles are being constantly developed and improved to reach new levels of excellence. Whether it's top speed, aerodynamics, fuel consumption or safety, every area is constantly being upgraded. If there is one prominent theme throughout, it is the environment. All new cars that roll off the production line today are carefully monitored to ensure their greenhouse gas emissions and environmental impact are in line with regulations. Subsequently, many of the new processes and systems are geared toward hybrid and electrical power. Some traditionalists think an

On board a 2014 F1 car

Take a look at the key changes to the latest Formula 1 racers



Rear wing

Many of the new cars have developed their back wing to allow for better aerodynamics. There are now large openings in the sidepods that allow hot air to exit more easily.

Exhaust

One tailpipe must now be used instead of two. Regulations state it must now be angled upwards with no car body behind it.

Rear tyres

A new style sees air being blown onto the brakes of the rear wheels. This helps cool the system.

ERS

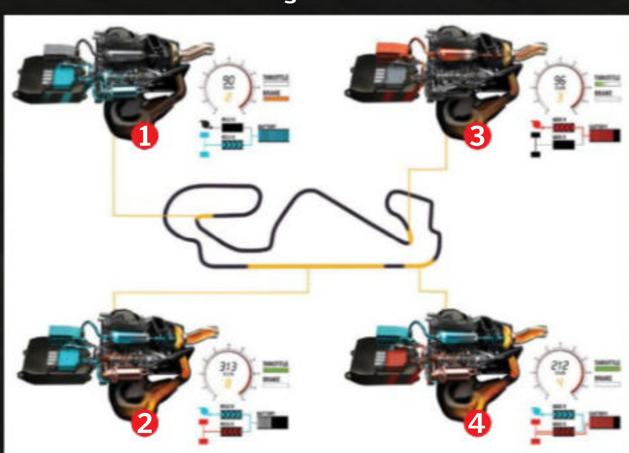
Part of the new hybrid system, this will produce an extra 119kW (160bhp) for 33 seconds per lap from supercharger waste heat and braking.

Gearbox

Eight forward ratio gears will be used rather than seven. These must be chosen before and not changed throughout the season.

A lap with the ERS

How does the energy recovery system give an F1 car a much-needed boost during a race?



1 Braking
When the car enters a corner, the kinetic energy from the driver braking is converted and stored in the battery.

2 Acceleration
As the car hurtles down the straight, the MGU-H takes heat energy from the exhaust and passes it to the MGU-K or battery.

3 Exiting a corner
When the driver accelerates again, 'turbo lag' occurs due to a lack of energy after braking. The stored electrical energy gives the turbo a boost until it can recover.

4 Overtaking
Driver intervention is not needed. However, the driver can override the system to get a boost for overtaking.

1955
Disc brakes are first used. This drastically increases braking power, as a result reducing stopping distance.

1960
The first significant safety measures are introduced. Cars now have a fire extinguisher and a circuit breaker on board.

1987
Computer-controlled active suspension is soon followed by anti-lock brakes and semi-automatic gearboxes.

2008
To add excitement for fans, traction control is banned to ensure more dramatic starts and more overtaking.

2009
KERS (Kinetic Energy Recovery System) kicks off the idea of storing power for a boost later in the race.

DID YOU KNOW? *The first hybrid system was made by German inventor Henri Pieper in 1909*

increased emphasis on eco tech will prevent existing records from being broken, but read on and you will see that while the racing cars of the future may be greener, they haven't compromised on their fundamental purpose: to be the first across the finish line.

Formula 1

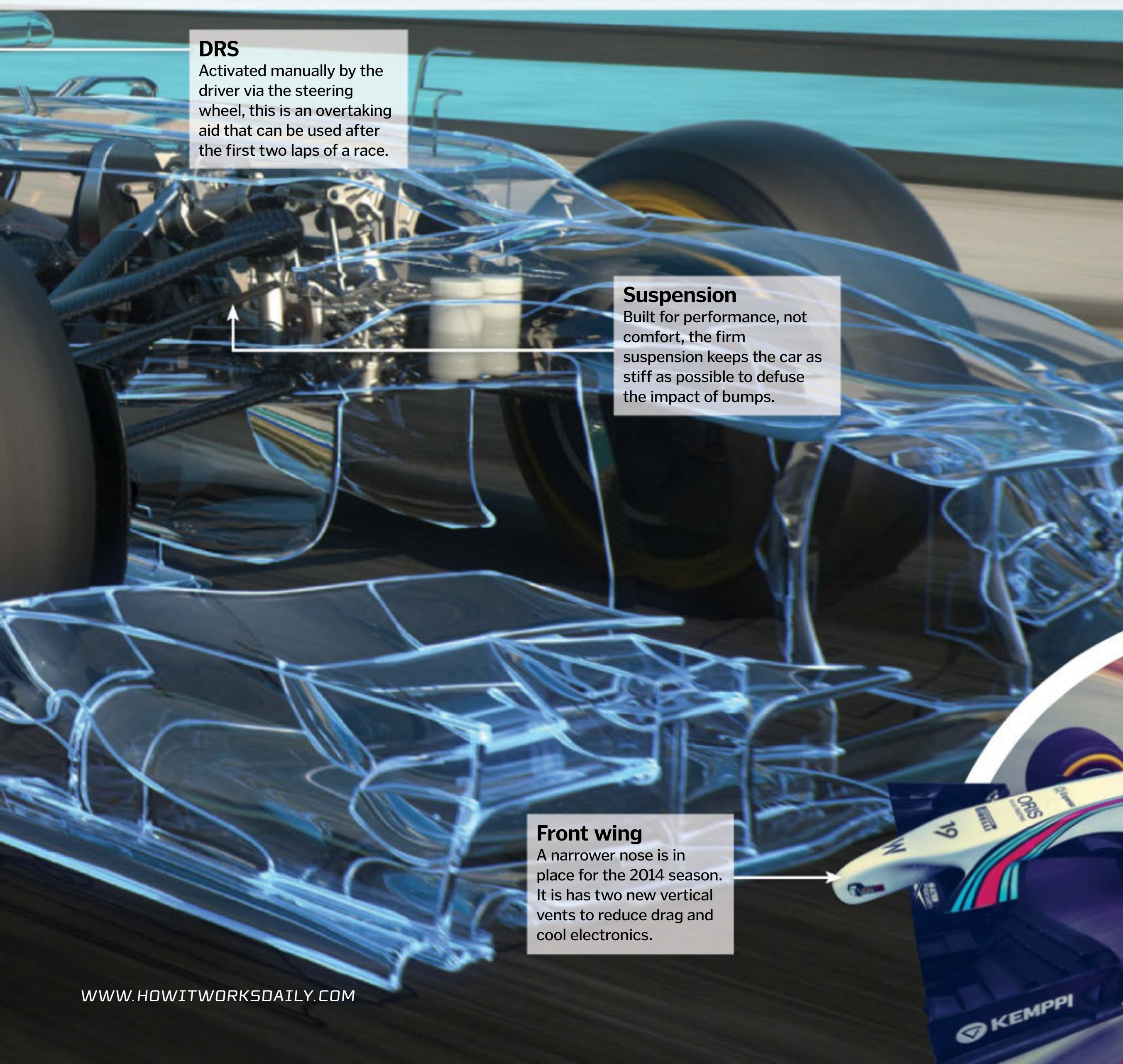
The Australian Grand Prix kicked off in Melbourne on 14 March and new technology has taken centre stage in what is being hailed by some as the biggest shakeup of regulations in the history of F1. Every car now has on-board chargeable batteries, which will recycle energy that's normally wasted.

The new Energy Recovery System (ERS), taking over from the older Kinetic Energy Recovery System (KERS), is designed to capture waste energy during braking and turn it into electric power for the car. The ERS will provide drivers with an added 119 kilowatts (160 horsepower) per lap and will be delivered automatically rather than manually. Moreover, a heat motor generator unit (MGU-H) will also transfer exhaust heat into energy. These new systems will be essential, as engines have been reduced to one exhaust tailpipe and from 2.4-litre V8s to 1.6-litre V6s. The rev limit will also now be at a maximum of 15,000rpm. Gearboxes in 2014 cars will have eight forward ratios rather than seven.

All these measures will look to decrease emissions and fuel use while still maintaining high-octane racing performance; indeed, 35 per cent less fuel will be burned with a new limit of 100 kilograms (220 pounds) per race rather than the previous 160 kilograms (353 pounds). The ERS and MGU-H will almost completely subsidise the reduction in power, highlighting the power of hybrid engines.

As well as these general modifications, each of the constructors is incorporating their own changes to their cars. For instance, Toro Rosso is introducing two oil radiators to help with cooling and a new nose to improve airflow. Mercedes has a new aerodynamic package, Williams is experimenting with a simpler cooling system and Ferrari is trialling a different location for the battery pack as well as an upgraded front wing.

Pierre-Jean Tardy, director of testing and development at Renault F1, claims the new regulations have been, "a complete revolution for Renault", and that the new rules formed, "a blank sheet and no single piece is the same between the old and new power units. It's been a big expenditure and investment." ▶



The statistics…

Formula 1 car

Power: 1.6l V6 turbocharged engine with ERS
Transmission: Semi-automatic eight gears
Length: 463cm (182in)
Width: 180cm (71in)
Weight: 691kg (1,523lb)
Fuel: 100kg (220lb) per race

> "With the new regulations, the car with the most powerful engine won't necessarily make the fastest car"

Racing beyond F1

Following F1's lead, all of the major global car companies are fully embracing new state-of-the-art technology in their motorsport divisions. Porsche is just one of them. The 919 is a hybrid and has two electric motors that supplement the 353-kilowatt (480-horsepower) engine. The electric energy is stored in a lithium-ion battery pack and applied to the petrol engine when required. The model has been raced extensively around the Nürburgring and has entered this year's Le Mans endurance race. It uses the new F1 ERS system and is concentrating on turbocharging to utilise the best use of engine power. It will also include regenerative braking strategies and an improved fuel economy.

In February, Toyota revealed that it is racing its new TS040 in the 2014 FIA World Endurance Championship. A progression from the previous 2012 model, it will be four-wheel drive and have an electric power boost in a similar vein to the ERS. This boost will allow the V8 engine to be as efficient as possible while still having the extra electric grunt behind it. Toyota is even talking of a decrease of five to ten seconds in its lap times with the new system. Therefore, with the new regulations, the car with the most powerful engine won't necessarily make the fastest car anymore. The fact that existing models are being given the hybrid treatment (as opposed to creating a whole new car from scratch) demonstrates the rising popularity of hybrids in the motoring world.

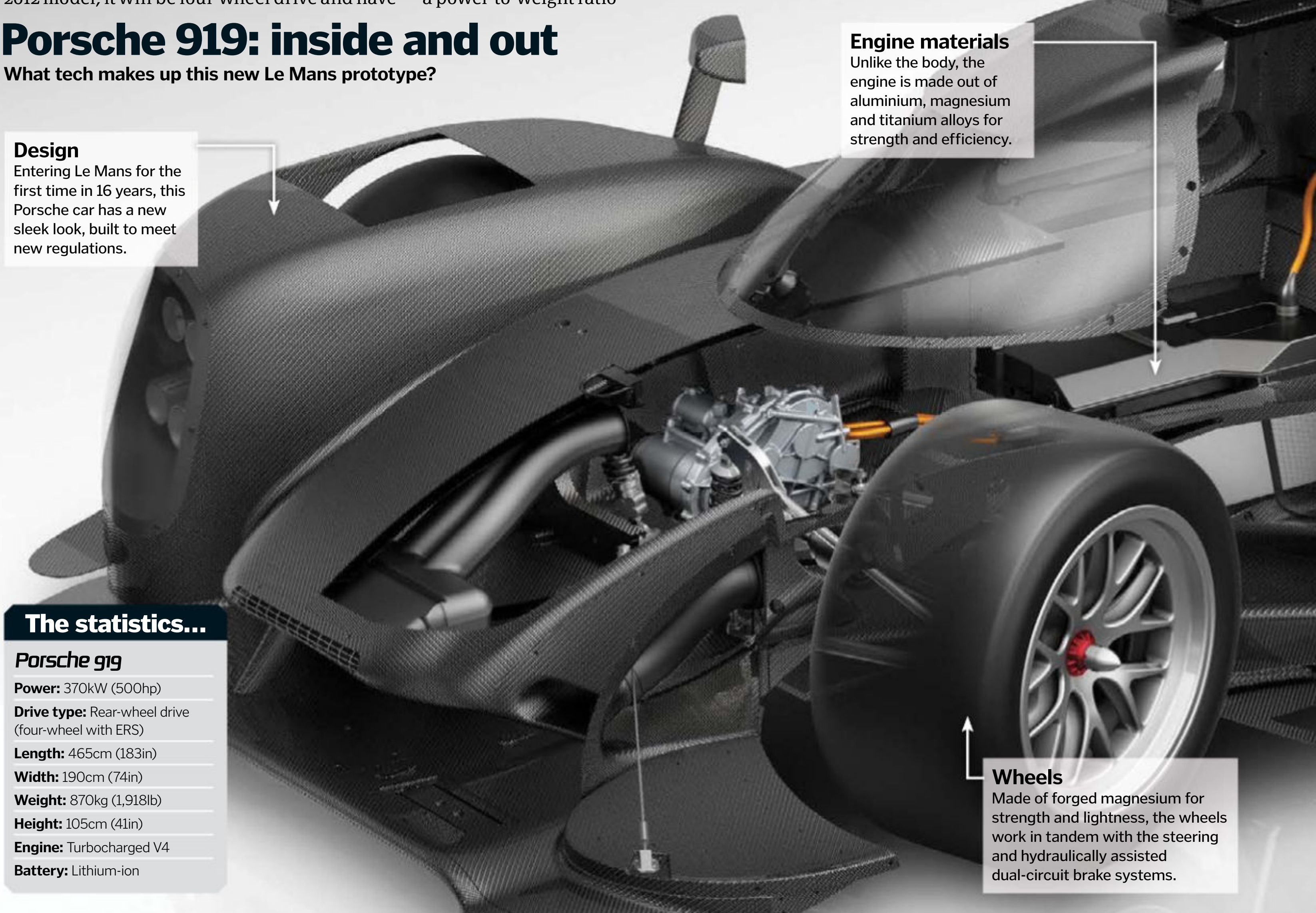
Peugeot is a company that isn't always mentioned in the upper echelons of racing. In 2015, however, Peugeot Sport will be taking on the fearsome Dakar Rally. The car is expected to be an upgrade of the 208 T16. Its specifications are impressive with a power-to-weight ratio of 756 kilowatts (1,000 horsepower) per ton, which is more than an F1 car and nearly twice as much as a Bugatti Veyron! To keep all this power on the road, the downforce will be supplied by a two-metre (6.6-foot) spoiler alongside an aerodynamic underbody tray.

Other than Le Mans, the 24 Hours of Daytona, has the MazdaSKYActiv car, which uses turbodiesel fuel. The Ford Daytona EcoBoost is also attempting to be different by incorporating a V6 rather than a V8.

Also stateside NASCAR is another motorsport implementing big changes. As well as having the largest environmental sustainability programme in US sports, new strategies have been put in place. New windshields are made out of a high-strength polycarbonate laminate shield known

Porsche 919: inside and out

What tech makes up this new Le Mans prototype?



Design
Entering Le Mans for the first time in 16 years, this Porsche car has a new sleek look, built to meet new regulations.

Engine materials
Unlike the body, the engine is made out of aluminium, magnesium and titanium alloys for strength and efficiency.

Wheels
Made of forged magnesium for strength and lightness, the wheels work in tandem with the steering and hydraulically assisted dual-circuit brake systems.

The statistics...

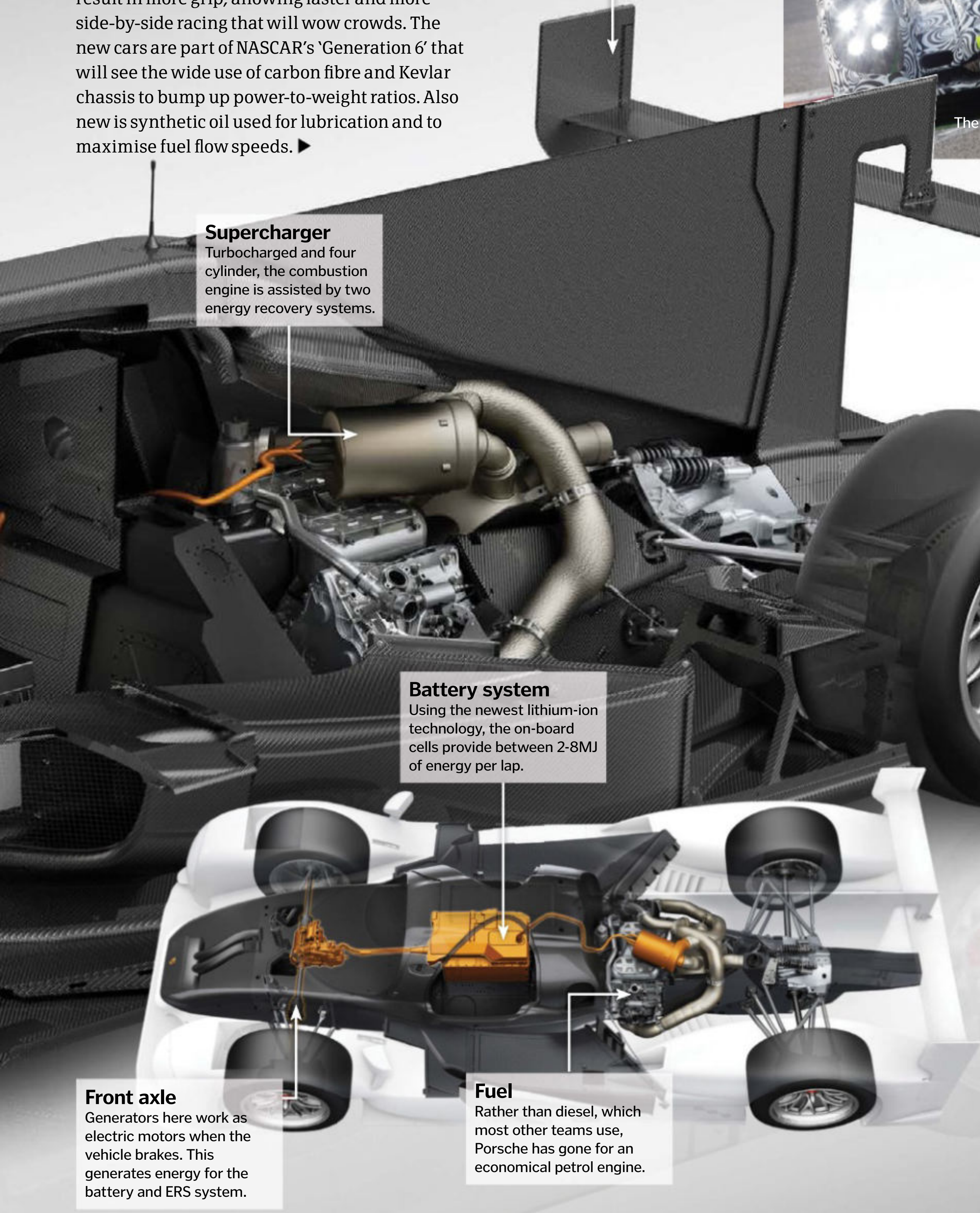
Porsche 919

Power: 370kW (500hp)
Drive type: Rear-wheel drive (four-wheel with ERS)
Length: 465cm (183in)
Width: 190cm (74in)
Weight: 870kg (1,918lb)
Height: 105cm (41in)
Engine: Turbocharged V4
Battery: Lithium-ion

DID YOU KNOW? Formula 1 cars are geared more towards fast cornering than straight-line speed

as Lexan. Much like in Formula 1, NASCAR is also witnessing a raft of new regulations. From now on, there will be no ride height rules, which will allow the teams to incorporate as much downforce as they like to their cars. This will result in more grip, allowing faster and more side-by-side racing that will wow crowds. The new cars are part of NASCAR's 'Generation 6' that will see the wide use of carbon fibre and Kevlar chassis to bump up power-to-weight ratios. Also new is synthetic oil used for lubrication and to maximise fuel flow speeds. ▶

The Porsche 919 shares a lot of its hybrid tech with the road-legal Porsche 918 Spyder



Carbon-fibre body

The 919 is extremely lightweight. Made of a carbon-fibre and a honeycomb aluminium core, its minimum weight is a tiny 870kg (1,918lb), which is less than a Mini Cooper!

Supercharger

Turbocharged and four cylinder, the combustion engine is assisted by two energy recovery systems.

Battery system

Using the newest lithium-ion technology, the on-board cells provide between 2-8MJ of energy per lap.

Front axle

Generators here work as electric motors when the vehicle brakes. This generates energy for the battery and ERS system.

Fuel

Rather than diesel, which most other teams use, Porsche has gone for an economical petrol engine.

Safety matters

As cars get faster, lighter and more powerful, safety procedures need to keep pace. For instance, the Porsche 919 has a closed monocoque shell, which has added strength granted by a similar material to that used in bulletproof vests. The enlarged chassis gives the driver more room to manoeuvre in the event of a crash and a better field of view to prevent an incident occurring in the first place.

Formula 1 uses a safety car (see below) in its races to help divert the rest of the racers if there is an accident. They are now integral to any Grand Prix as they allow the quickest possible response to incidents without disrupting the rest of the pack.

The seemingly dead-slow F1 safety car has a top speed of 317 km/h (197 mph)

"Formula E's ultimate goal is to make electric vehicles the norm, not just in racing, but in everyday driving"

▶ The rise of electric cars

Perhaps the most radical addition to the racecar roster this season is Formula E. Devised by the FIA (Fédération Internationale de l'Automobile), it will begin its inaugural season in September. It is the world's first fully electric racing series and in 2014 it will have ten teams racing through ten cities including London and Los Angeles.

The new competition is showing its potential by attracting big names like Sir Richard Branson who is entering a Virgin racing team. Famous drivers like ex-Formula One drivers Jarno Trulli, Bruno Senna and Jérôme d'Ambrosio are also lending their support and test-driving the cars.

The cars themselves are pushing the boundaries of electric motorsport. It will use a power-saving mode during the race to lengthen race times and a 'push-to-pass' system that gives a temporary max power boost to help overtaking. The batteries, as on hybrids, are rechargeable 800-volt lithium-ion cells. All the cars will have identical specifications in the first season, but if a second is commissioned, constructors will be allowed the chance to modify the vehicles. Formula E's ultimate goal is to make electric vehicles (EVs) the norm, not just in racing, but in everyday driving too. Its official target is to put 52-77 million extra EVs on the road over the next 25 years. According to Formula E and FIA calculations, this will reduce annual CO_2 emissions by 900 million tons, save 4 billion oil barrels and save £20.7 billion ($34.4 billion) on healthcare costs due to the expected reduction in pollution levels. ▶

Game-changing electric car

Tesla sprang to attention in 2008 when it released the impressive Roadster, which effectively showed the world that electric cars could be workable, reliable and, above all, cool.

Now the new Model S and Model X are stepping things up a gear. The S looks like a saloon car but can still hit speeds of 209km/h (130mph) and has a range of around 483km (300mi). Meanwhile, the X is an SUV and will boast a battery of up to 85kW (114bhp).

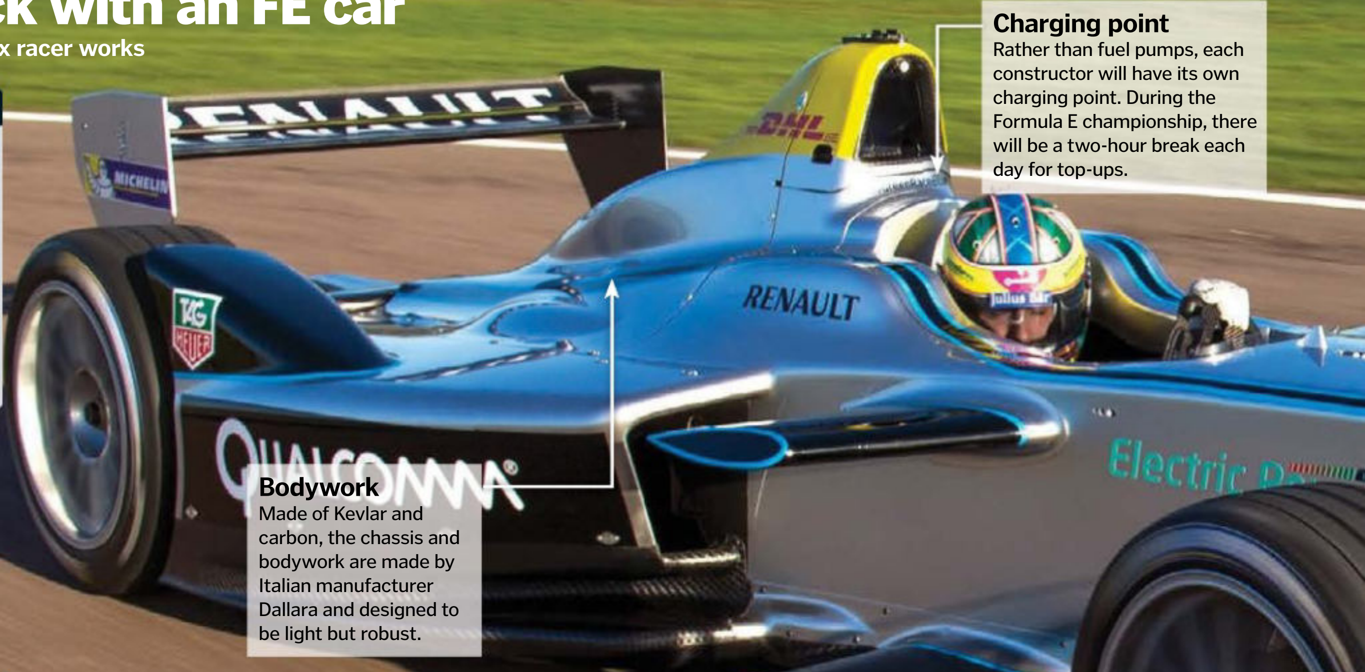
On the track with an FE car

How an electric Grand Prix racer works

The statistics...

Formula E car

Max power: 200kW (270bhp)
Top speed: 225km/h (140mph)
Length: 500cm (197in)
Weight: 800kg (1,764lb)



Charging point
Rather than fuel pumps, each constructor will have its own charging point. During the Formula E championship, there will be a two-hour break each day for top-ups.

Bodywork
Made of Kevlar and carbon, the chassis and bodywork are made by Italian manufacturer Dallara and designed to be light but robust.

ON THE MAP

Formula E teams

1 Drayson Racing (UK)
2 China Racing (China)
3 Andretti Autosport (USA)
4 Dragon Racing (USA)
5 E.Dams (France)
6 Super Aguri Formula E (Japan)
7 Audi Sport ABT (Germany)
8 Mahindra Racing (India)
9 Virgin Racing (UK)
10 Venturi Grand Prix (Monaco)

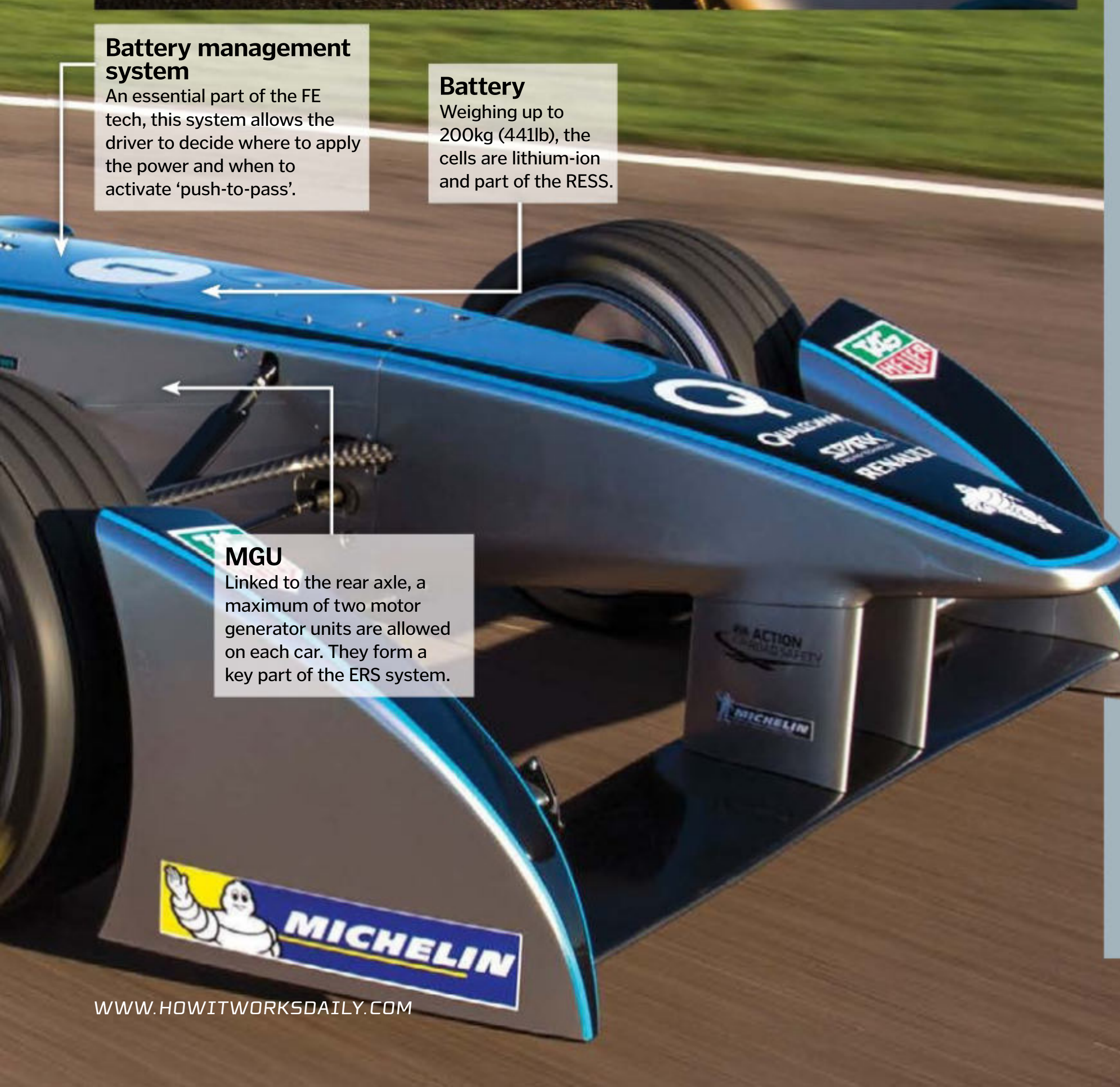
46YRS

OLDEST-EVER WORLD CHAMPION

Argentinian racing legend Juan Manuel Fangio became the oldest-ever Formula 1 champion after winning the 1957 German Grand Prix, when he was aged 46 years old.

DID YOU KNOW? Hollywood actor Leonardo DiCaprio is a cofounder of Formula E team Venturi Grand Prix

Formula E involves many companies working in Formula 1 and the electric cars' design is an obvious testament to the traditional racers



The electric revolution

A revealing interview with Formula E CEO Alejandro Agag on the future of motorsport

Tell us what Formula E is all about.
Formula E is the world's first fully-electric racing series beginning in Beijing in September 2014. For the first season, there are ten races all taking place on street circuits in the heart of cities around the globe. We have ten teams – backed by top names including Michael Andretti, Alain Prost, Sir Richard Branson and Leonardo DiCaprio – each with two drivers. We want to create a new and exciting racing series that will appeal to a new generation of motorsport fans.

Where did the idea for FE come from?
The idea for Formula E came from the FIA. In essence, the concept behind Formula E is to promote the electric-car industry and to act as a framework for research and development around EV technology. One of the biggest barriers preventing the uptake of electric cars are the stigmas attached to them. People don't see them as 'cool' or 'exciting' and they are worried about battery life and, of course, cost. Formula E hopes to [rectify] this and act as a catalyst for change.

How are FE cars made?
The Spark-Renault SRT_01E is a very sophisticated fully electric open-wheel racing car. It has been built and designed by French-based Spark Racing Technology together with a consortium of the leading names in motorsport including McLaren (powertrain & electronics), Dallara (chassis), Williams (battery design), Renault (system integration) and Michelin (tyres). For the first season, all the cars are identical but from season two teams will be able to build their own cars. It is this new technology that we eventually want to filter down into everyday electric road cars.

What does the future hold for FE?
We hope the future of Formula E is the future of motorsport. We also want the series to act as a catalyst to promote sustainability and make people think about the environment they live in – particularly in cities. Our aim is to appeal to the next generation of motorsport fans but also car buyers so that their first car is an electric one.

Despite being fully electric, a Formula E car will still generate about 80db

"Tech that was once solely used for racing and out of reach for the public is now becoming much more familiar"

Coming to a car near you…

Taking a leaf out of motorsport's book, modern production cars are incorporating new technology with a racing pedigree. Two standout examples are the McLaren P1 and Ferrari LaFerrari. They use a similar version of the new ERS to enhance acceleration and both have had extensive modifications to their aerodynamics and materials.

Carbon fibre has been a mainstay in racing ever since it was attributed with saving F1 driver John Watson's life in 1981. The McLaren driver lost control and crashed into a barrier but the material's tough properties allowed him to escape unharmed. Since then, production cars have been hesitant to embrace the material due to its high cost and lack of continuous supply but it is starting to replace aluminium and other metals as the boundaries between racing and everyday cars increasingly blur.

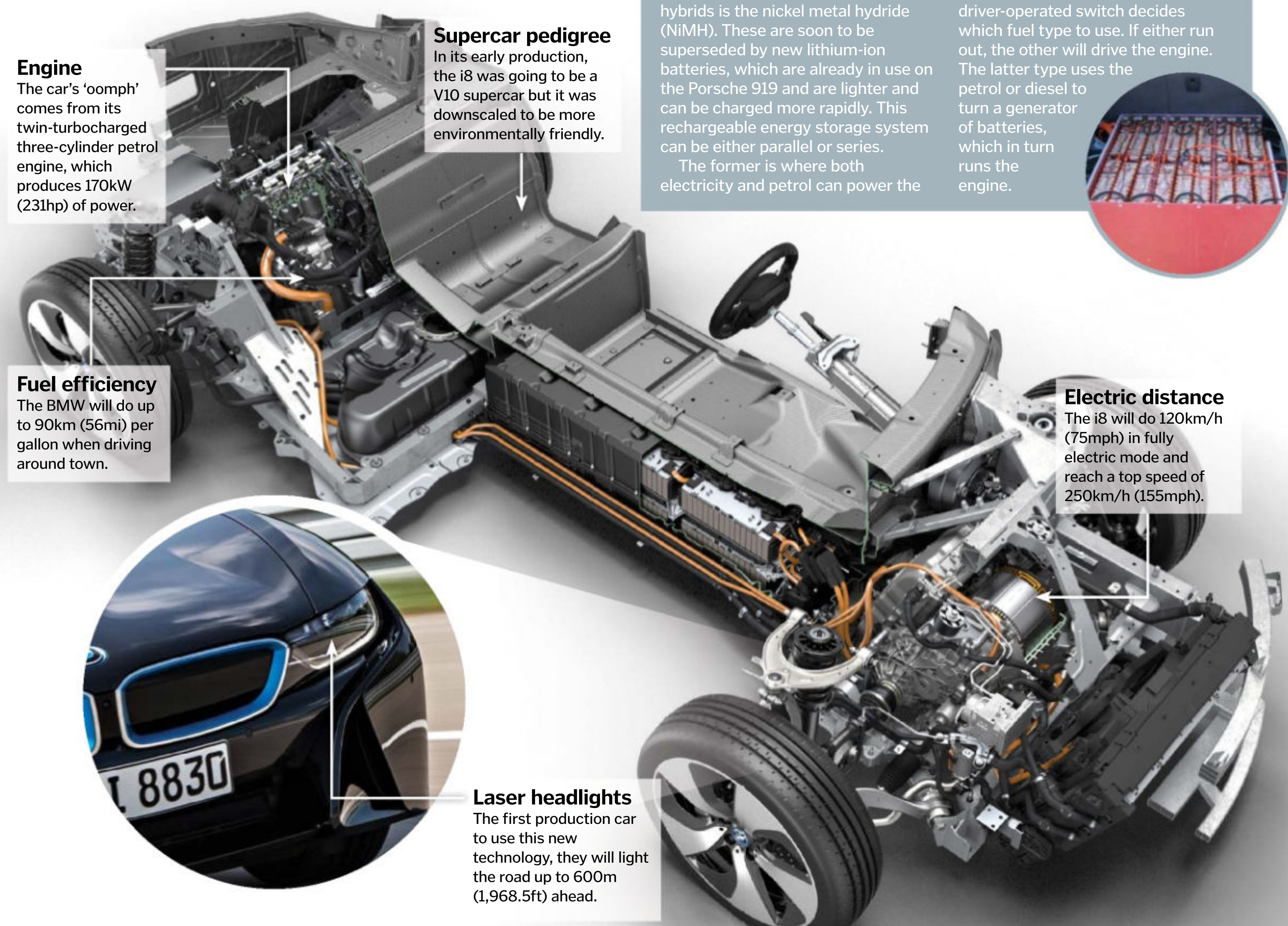
It might come as a surprise to many, but the Nissan DeltaWing – which competes in Le Mans and the United SportsCar Championship – shares its engine with the Nissan Juke. The Juke is an SUV and its engine was the blueprint for the racing DeltaWing. As both are turbocharged, this is a clear demonstration that today racecars and mass-produced cars can learn from each other. Tech that was once solely used for racing and out of reach for the public is now becoming much more familiar.

Many of the modern and upcoming releases were shown at the 2014 Consumer Electronics Show (CES) in January. For instance, the dashboard and panel display are also getting big upgrades. Google is looking to utilise its Android technology as a 'virtual cockpit' in new cars. Usually reserved for smartphones and tablets, the operating system will integrate your favourite apps into your car's system. It will include 4G, LCD panels and twin quad-core CPUs. The new Audi TT is pioneering the new systems and Honda and Hyundai have also registered an interest. A rival system known as UConnect is being used on the Dodge Viper.

Moreover, the age of CD players could be nearing an end. Known as 'Signal Doctor', the future system aims to have 'studio quality' songs for digital music players in cars.

Racing tech in road cars

We go under the hood of the new BMW i8



Next-gen batteries

The most common battery used in hybrids is the nickel metal hydride (NiMH). These are soon to be superseded by new lithium-ion batteries, which are already in use on the Porsche 919 and are lighter and can be charged more rapidly. This rechargeable energy storage system can be either parallel or series.

The former is where both electricity and petrol can power the engine separately. Usually, a driver-operated switch decides which fuel type to use. If either run out, the other will drive the engine. The latter type uses the petrol or diesel to turn a generator of batteries, which in turn runs the engine.

5 TOP FACTS
MAKING AN F1 CAR

Conceptual stage
1 An F1 car takes over five months and 300 designers to develop. Supercomputers are used to envision the finished vehicle and create a template for construction.

Tunnel run
2 Aerodynamics is tested on a 60 per cent scale version of the car. Racing situations are simulated to see how the racer will hold up in future competitions and events.

Materials
3 Lightweight but ten times stronger than steel, carbon fibre is an ideal composite material for F1 cars. First used in 1981, it is sterilised and pressurised in an autoclave.

Manufacture
4 As well as automatic machinery, the majority of an F1 car is handmade. The paint used has to fit weight and smoothness regulations as well as looking good.

Assembly
5 In the end, five copies of the finished chassis are created: one for each driver, two for the race-weekend backup cars and lastly a spare one for emergencies.

DID YOU KNOW? In the UK, car tax is much lower on hybrid cars due to their lower CO_2 emissions

Perhaps the biggest state-of-the-art change, though, is the possibility of self-driving cars. At CES, BMW demonstrated a 2-Series and a 6-Series completing laps without any human intervention. The cars used ultrasonic 360-degree sensors to understand their surroundings and even drifted and powerslided on their run. This new equipment will aim to aid safety by helping the driver make key decisions on the road, such as lane discipline and parking.

There have also been further advances in hybrid cars, as well as alternatives to hybrids. French firm Renault, for example, has found a way to reduce CO_2 levels without using hybrid tech. Vice president of Renault's powertrain strategy, Marc Bodin, told us: "Hybrid, for us, is not at the right level of balance between cost and customer value at the moment." Renault, which has the lowest CO_2 emissions of Europe's car companies, is exploring alternative internal combustion engine (ICE) improvement and EV (electric vehicle) development. Both the Clio and Mégane models are at the same CO_2 level as a standard hybrid but less expensive for the customer. Bodin did concede, however, that the new emission targets in 2020 would require some sort of hybrid mechanism.

The BMW i8 (pictured below) looks to be a revolution in combining racing tech with low emissions. It has a CO_2 efficiency of A+, which is the highest band available in production cars, but can still reach speeds of 250 kilometres (155 miles) per hour and get from 0-100 kilometres (0-60 miles) per hour in 4.4 seconds!

New types of fuel are being developed too, such as compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gas (LPG), solar power and hydrogen. LNG has a higher storage density than fuels and is cleaner and cheaper than petrol while hydrogen can increase mileage by up to 25 per cent.

For example, the Honda Civic GX is the first production car to run on CNG, the Ford C-Max Solar Energi Concept utilises sunlight to get around and the Toyota FCV has a hydrogen fuel cell. The rise of these alternative fuels looks set to make future motoring greener than ever.

The BMW i8 has been in constant development since 2009's Vision EfficientDynamics concept car was presented

The statistics…
BMW i8

Max speed: 250km/h (155mph)
CO_2 emissions: 59g/km
Length: 469cm (185in)
Width: 194cm (76in)
Unladen weight: 1,490kg (3,285lb)
Height: 130cm (51in)
Electric range: 35km (22mi)

GPS to control your gears

First we had little more than local knowledge, then we had maps and then GPS systems came along. Now we have satellite-aided transmission, or SAT.

This new technology, pioneered by Rolls-Royce on its latest Wraith cars (below), calculates what is beyond the driver's line of sight. Whether it's around a corner or for the next motorway junction, SAT anticipates what's ahead and chooses the best gear for you. The system can be used in both production and racing cars and could increase lap times and fuel efficiency by preparing the car for what's around the next bend, though many would argue this should be down to the driver's skill rather than a computer.

Hybrid types

Mild hybrids
These permit the energy generated while braking to be recovered and temporarily stored. This provides the vehicle with additional power the next time it accelerates, which in turn leads to a significant fuel-consumption saving.

Micro hybrids
Cars that are powered by an internal combustion engine but are equipped with certain functions that use a battery for energy.

Full hybrids
Vehicles that are equipped with both an internal combustion engine and an electric motor, which allows them to run on electricity alone at low speeds, or to combine both sources to provide a power boost when accelerating.

Plug-in full hybrids
These are equipped with a battery that allows electricity drawn from the grid to be stored and then used to run for a short distance on electricity alone.

"They are sent to vast expanses of land for safe keeping or to have their parts repurposed into new aircraft"

The Aerospace Maintenance and Regeneration Group in Arizona is nicknamed 'The Boneyard'

1. BIG

Murtala Muhammed Airport
A fully operational airport in Nigeria's capital Lagos also is home to 13 of the country's 65 broken aeroplanes.

2. BIGGER

AMARG
Site of over 4,000 retired commercial and military aircraft, you can tour the Aerospace Maintenance and Regeneration Group by bus from the affiliated museum.

3. BIGGEST

Mojave Air & Space Port
Covering 13.4km^2 (5.2mi^2), this aerospace test centre is the final stop for thousands of commercial jets.

DID YOU KNOW? *Allegiant Air runs the oldest major airline fleet in the world, with an average plane age of 23 years*

Plane graveyards

Where do old aircraft go to retire and how do they help provide for the next generation of aeroplanes?

The advent of Google Earth has allowed for many stunning images of the planet on which we live, but few have caused such a reaction as the sites of plane graveyards, scattered across the world.

As various commercial and military aircraft are damaged or retired, they are sent to vast expanses of land for safe keeping or to have their parts repurposed into new aircraft.

One of the most jaw-dropping examples of these sites is the Aerospace Maintenance and Regeneration Group (AMARG) in Tucson, Arizona. This sprawling 10.5-square-kilometre (four-square-mile) US airbase houses more than 4,000 retired aircraft, including the B-52 Stratofortress, B-1B Lancer bomber and the A-10 Thunderbolt. Another such site is the Mojave Air & Space Port, which is the final resting place for hundreds of former commercial liners.

These facilities are essential for the safe post-retirement care of thousands of aircraft, many of which contain valuable hardware and – since many are warplanes – military tech that could be dangerous in the wrong hands.

Wherever possible, these planes have their working parts harvested for use on newer aircraft, but looking down from straight above at thousands of massive sky vehicles grounded for life is an incredible sight, if a slightly heart-wrenching one.

Tours are available for some aircraft graveyards, such as the AMARG, giving aircraft enthusiasts one last opportunity to see a potted history of aviation, dating back to WWII.

Lasham Airfield in Hampshire, UK, hosts 26 aeroplanes from now-defunct budget airlines

“As the surface is generally loose and uneven, a dune buggy must be light, have good traction and move swiftly”

Dune buggy engineering

Find out how these nimble off-roaders have been specially adapted to make light work of a terrain where most vehicles would quickly get stuck

Dune buggies are vehicles that have been specially adapted to traverse sandy terrain. As the surface is generally loose and uneven, a dune buggy must be light, have good traction and move swiftly.

Dune buggies first became popular in the Sixties when predominantly American enthusiasts would convert air-cooled VW Beetles for off-road use due to their simplicity to modify and maintain. However, today’s dune buggies are specifically engineered vehicles in their own right, delivering performance as well as practicality. This is achieved via a chassis welded to a reinforced steel rollcage. As well as being a key safety device should the vehicle tip over, the main advantages of a rollcage over a solid roof is that it keeps the vehicle light and helps keep the occupants cool.

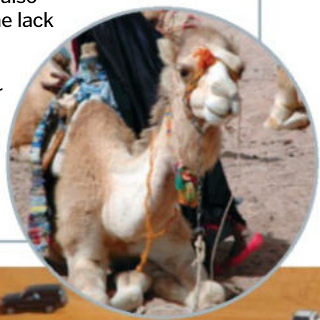
Engines are usually borrowed from small cars or even motorbikes, ideal for their high revs that provide plenty of pulling power. The engine tends to sit behind the driver and parallel with the rear axle to help spread weight between the two rear tyres.

Wide tyres are used with a very low pressure to ensure they cover a greater surface area. As the ground is so uneven, suspension shocks with huge travel are used to help absorb as much of the harsh ride as possible. The vehicle is operated via pedals and a rack-and-pinion steering column, like a normal car.

Today, dune buggies are mainly used in competitions, though there are more sedate models which can be hired by tourists. The military has also employed these vehicles for operations in desert regions.

Nature’s dune buggy

Camels long preceded the dune buggy and have proved just as capable, if somewhat slower, as a form of transport in sandy environments. Much like the tyres on a dune buggy, camels have adapted to this terrain thanks to large, padded feet that spread their weight over a greater surface area, enabling them to walk on top of the loose surface. Their woolly coat keeps them cool during the day and warm at night, while long eyelashes, hairy ears and slitted nostrils keep sand at bay. They have also evolved to cope with the lack of natural resources by storing fat in their humps as well as water and broken-down food in their stomach lining, so they can keep going for days without nourishment.



Built for the desert

Check out the key features that make a dune buggy so well suited to travel over sand

"A port comprises two main sections in order to run effectively: sea-based and land-based infrastructure"

How ports work

Discover how these gateways between land and sea bring vehicles together to transport cargo around the globe

As the seas continue to play a fundamental role in globalisation, ports become an ever-more important feature in modern transport. From these trade hubs, huge cargo ships come and go bearing all manner of goods, from essentials such as food and fuel to more exclusive products like cars.

A port comprises two main sections in order to run effectively: sea-based and land-based infrastructure. The former starts with buoys positioned at sea to help direct boats via the safest route, away from shallow waters or hazardous rocks – much like the lights on a runway or cat's eyes on a road. These are followed by breakwaters at the harbour entrance. These man-made walls of concrete or natural rock help to absorb the power from the most ferocious waves, ensuring the water within is calm so vessels don't get damaged.

Further into the ports are a series of docks that allow a ship into an enclosed area where it can be moored for loading or unloading cargo or passengers. These can include dry docks, which shut gates off to drain the seawater from the enclosure, leaving the lower hull and keel accessible for restoration. The land-based infrastructure is immediately more visible when visiting a port, with huge cranes permanently fixed onto the docks to pick up heavy containers from a ship.

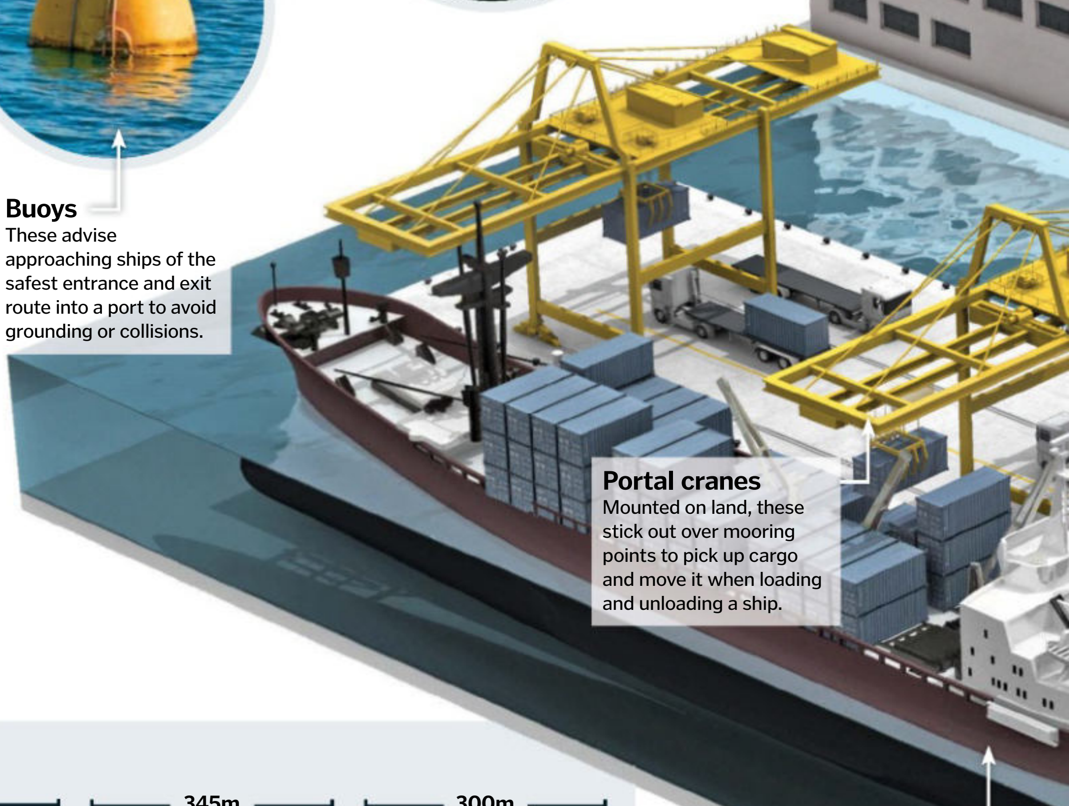
Ships with a drive-on capacity will be connected to a ramp mounted on the quay to enable road-going vehicles to board. Set back from the water, there will usually be easy access to railway lines and major roads so cargo can seamlessly carry on its journey inland.

A tour of the port

From out at sea to land-based transit links, find out some of the key infrastructure every good port needs

Breakwater
These take the power out of large waves to ensure water entering the docks is calm and moored ships are safe.

Buoys
These advise approaching ships of the safest entrance and exit route into a port to avoid grounding or collisions.



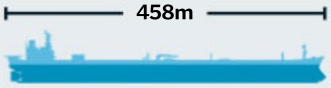
Radio tower
A harbour master communicates with captains on where to dock on arrival, or when the coast is clear to leave.

Portal cranes
Mounted on land, these stick out over mooring points to pick up cargo and move it when loading and unloading a ship.

Mooring
A dock provides an enclosed space of calm water for a ship to pull into and moor, a bit like a watery car park.

Mega vessel lineup

458m



Oil tanker
Oil tankers carry their liquid cargo in huge baffle tanks built into the ship between the hull and the deck. The baffle tanks are designed to stop the liquid from moving too much, or sloshing, which could upset the balance of the ship and capsize it.

397m

Container vessel
These are long, wide ships with a large flat deck on which to stack thousands of steel containers packed with cargo. They are stacked using heavy-duty cranes permanently mounted on the port.

345m

Cruise liner
Sometimes referred to as floating cities, these house and entertain thousands of travellers and come decked out with sleeping quarters, restaurants, casinos and even swimming pools.

300m

Bulk carrier
Transporting large quantities of loose goods such as food grains and ores, they can also be designed to hold liquids. These freighters typically use cargo holds built into the deck to carry their goods.

1. BIG

Hong Kong, China
The port of Hong Kong is responsible for shipping 23.1 million TEU (20ft equivalent units) containers every year.

2. BIGGER

Port of Singapore
Singapore oversees 31.6 million TEU per year, sending cargo on to more than 600 other ports in some 120 countries.

3. BIGGEST

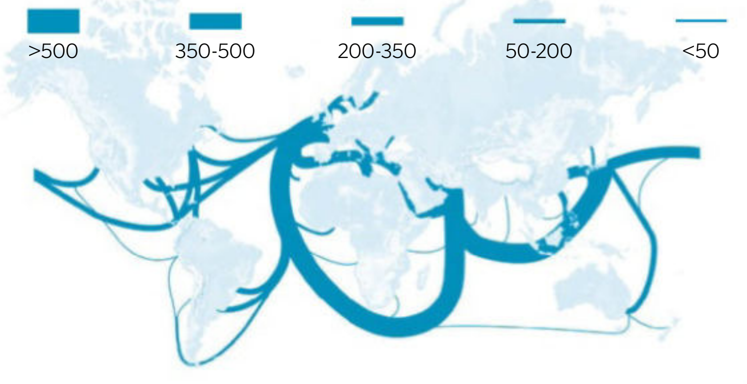
Shanghai, China
Both a river and ocean port, the world's busiest container port in China ships over 32.5 million TEU every year.

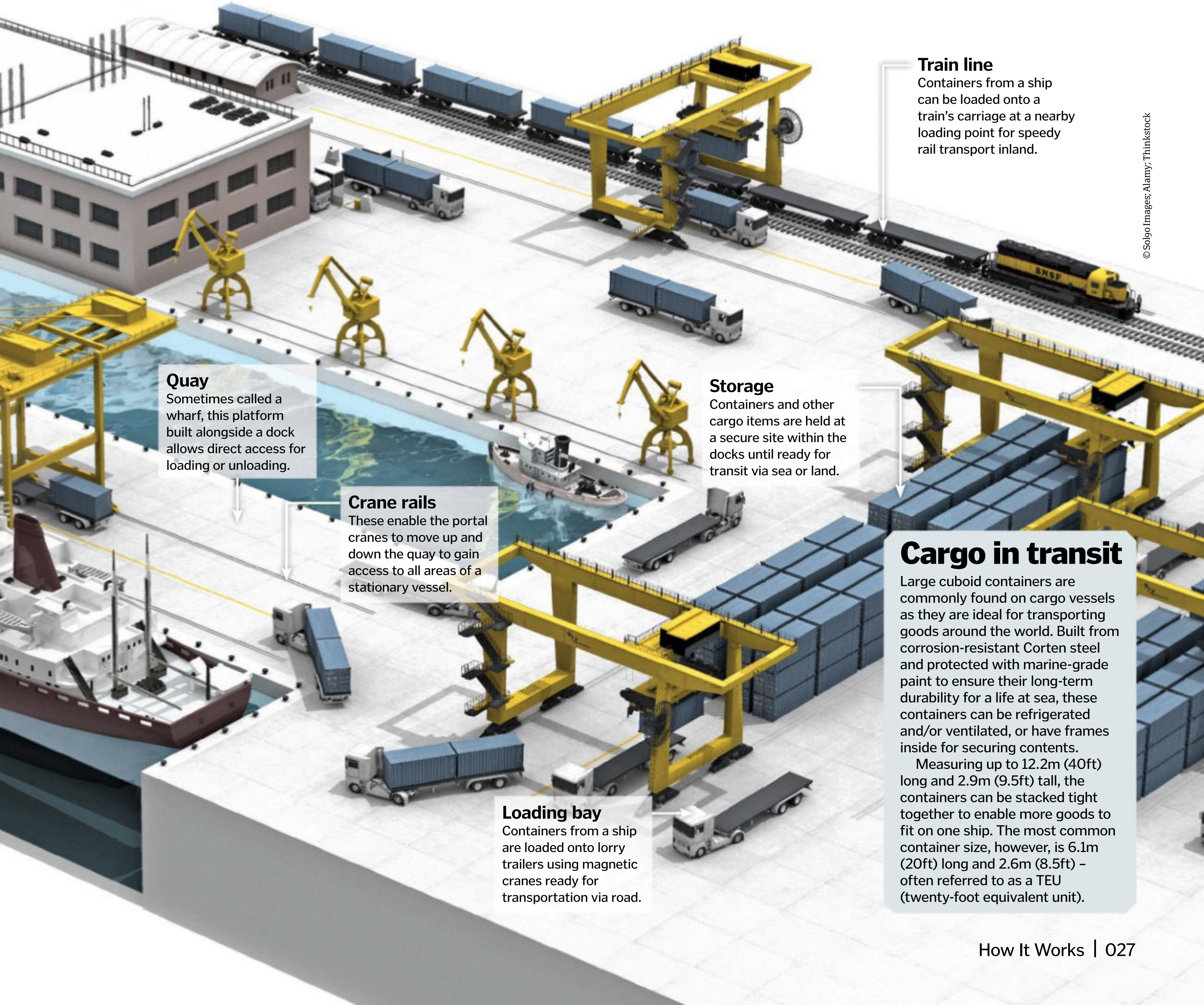
DID YOU KNOW? *In 2013, remains of 4,500-year-old boats and ropes at Wadi el Jarf, Egypt, hint at the oldest recorded port*

Roads of the sea

Shipping lanes refer to routes commonly used by merchant vessels, otherwise known as trade routes, in Earth's seas. These were initially selected for their favourable wind and current conditions for boats with sails, but are still used in modern times despite the rise of engine power. Boats not transporting cargo are advised to stay clear of the trade routes, as a collision with a huge cargo vessel (which are incredibly difficult to turn at short notice) could prove disastrous for a smaller boat.

The major routes are between Europe, Asia and North America, with one of the busiest routes eastbound from Asia to North America – a result of the Far East's huge export industry and its close connections with the United States.





Train line
Containers from a ship can be loaded onto a train's carriage at a nearby loading point for speedy rail transport inland.

Quay
Sometimes called a wharf, this platform built alongside a dock allows direct access for loading or unloading.

Storage
Containers and other cargo items are held at a secure site within the docks until ready for transit via sea or land.

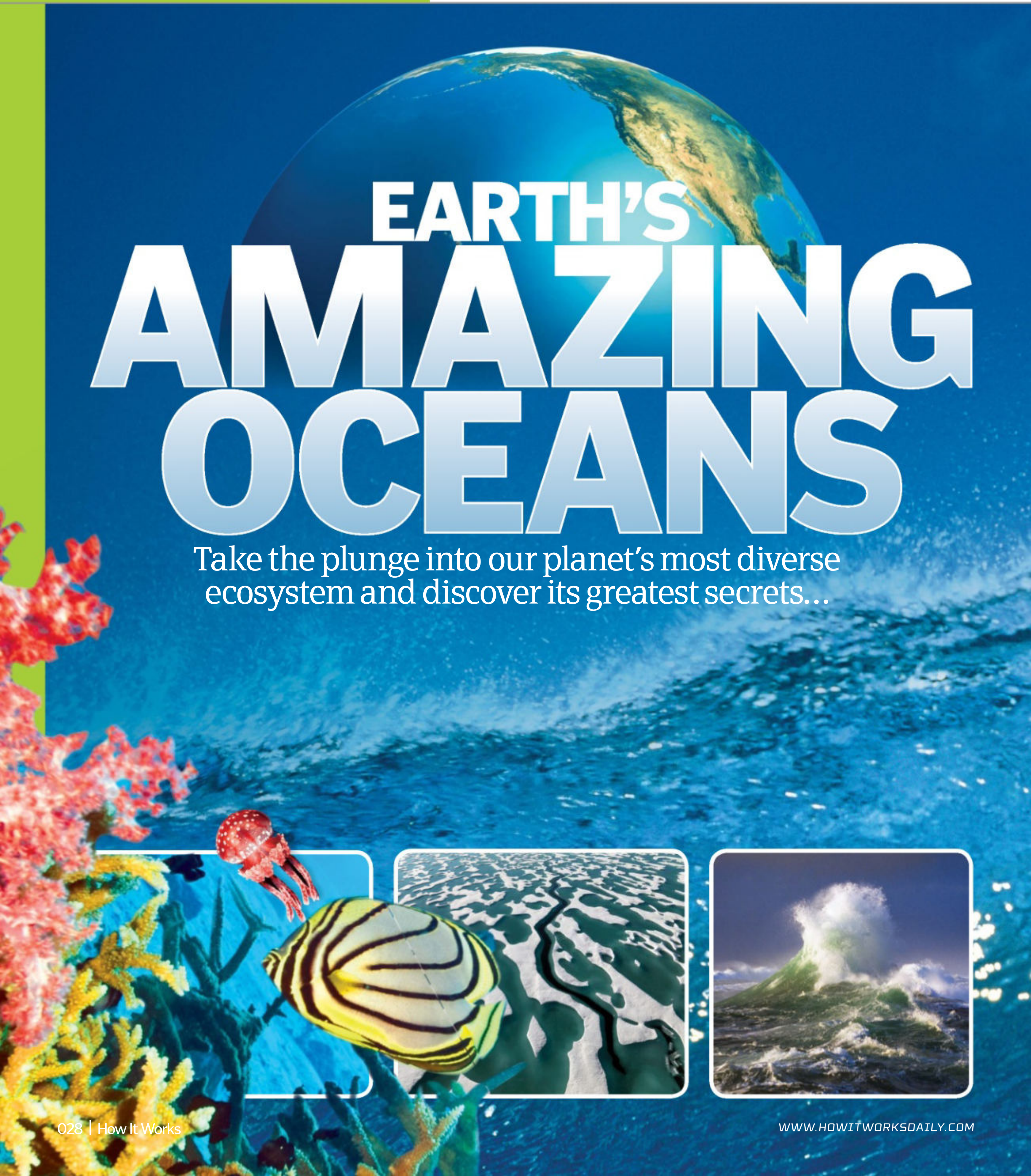
Crane rails
These enable the portal cranes to move up and down the quay to gain access to all areas of a stationary vessel.

Loading bay
Containers from a ship are loaded onto lorry trailers using magnetic cranes ready for transportation via road.

Cargo in transit

Large cuboid containers are commonly found on cargo vessels as they are ideal for transporting goods around the world. Built from corrosion-resistant Corten steel and protected with marine-grade paint to ensure their long-term durability for a life at sea, these containers can be refrigerated and/or ventilated, or have frames inside for securing contents.

Measuring up to 12.2m (40ft) long and 2.9m (9.5ft) tall, the containers can be stacked tight together to enable more goods to fit on one ship. The most common container size, however, is 6.1m (20ft) long and 2.6m (8.5ft) – often referred to as a TEU (twenty-foot equivalent unit).



EARTH'S AMAZING OCEANS

Take the plunge into our planet's most diverse ecosystem and discover its greatest secrets…

THE STATS
PACIFIC OCEAN

200mn YEARS OLD AGE OF OLDEST ROCK

4,080m AVERAGE DEPTH

ISLANDS 20,000

31% OF EARTH'S SURFACE

SEA VOLCANOES 450+

DID YOU KNOW? *The Coriolis effect is not present at the equator, meaning that these parts of Earth's oceans are gyre-free*

Many are aware of the oceans' vital statistics: over 70 per cent of our planet is covered in water, and over 95 per cent of the water on Earth is contained within the oceans. This water sustains life, from the highest predator to the smallest bug, as it cycles through our ecosystems and atmosphere. But just how did it all get there?

There are a few theories about how the water on Earth came to be, including many different influencing factors. The first is the inside-out model, suggesting that once the Earth formed water existed in a bond with other minerals, then came to the surface as a result of volcanic activity. Another idea is that water was present as vapour, which condensed as Earth cooled. A third theory is the outside-in approach, stating that some of our water came from outer space as ice contained within asteroids or comets. Regardless of which is true, the first permanent ocean on Earth is thought to have formed between 4.3 and 3.8 billion years ago.

The metamorphosis into the map we know today is the result of tectonic activity. Earth's crust floats on a layer of molten rock, known as the mantle. The crust is separated into several plates that, thanks to convection currents, are constantly moving against one another, spreading apart or disappearing underneath one another. At areas where the plates are pulling away, magma from beneath the crust wells up in the gap created by the separating plates. This cools, hardens and creates new layers of rock, which is how some oceans are growing at a surprisingly fast rate – sometimes more than 15 centimetres (5.9 inches) per year.

The water bodies of our five main oceans are all interlinked, cycling through a series of ▶

> "Surface currents are whipped up by wind and governed by landforms and the Coriolis effect"

currents. There are two types: surface and deep-water currents. Surface currents are whipped up by wind and governed by landforms and the Coriolis effect – a force that exists because of the Earth's spin on its axis. This force also has an effect on the water bodies within oceans and produces large-scale whirls of water that circulate around major ocean basins, known as gyres.

The deep-water variety of currents, meanwhile, is mainly a result of water temperature and salinity at the depths of ocean basins, known as thermohaline circulation. Salty, chilly water from the poles is dense, so it sinks to the bottom and slips along the seafloor. Water from the North Pole flows south, through the Atlantic down to the Southern Ocean. It then heads into the Indian and Pacific Oceans, where it heats up as it encounters warmer waters. Heated water that is less salty is less dense, so it rises but sinks again once it eventually reaches the poles and cools. It's estimated that it takes 1,000 years for water to complete this global ocean conveyor belt.

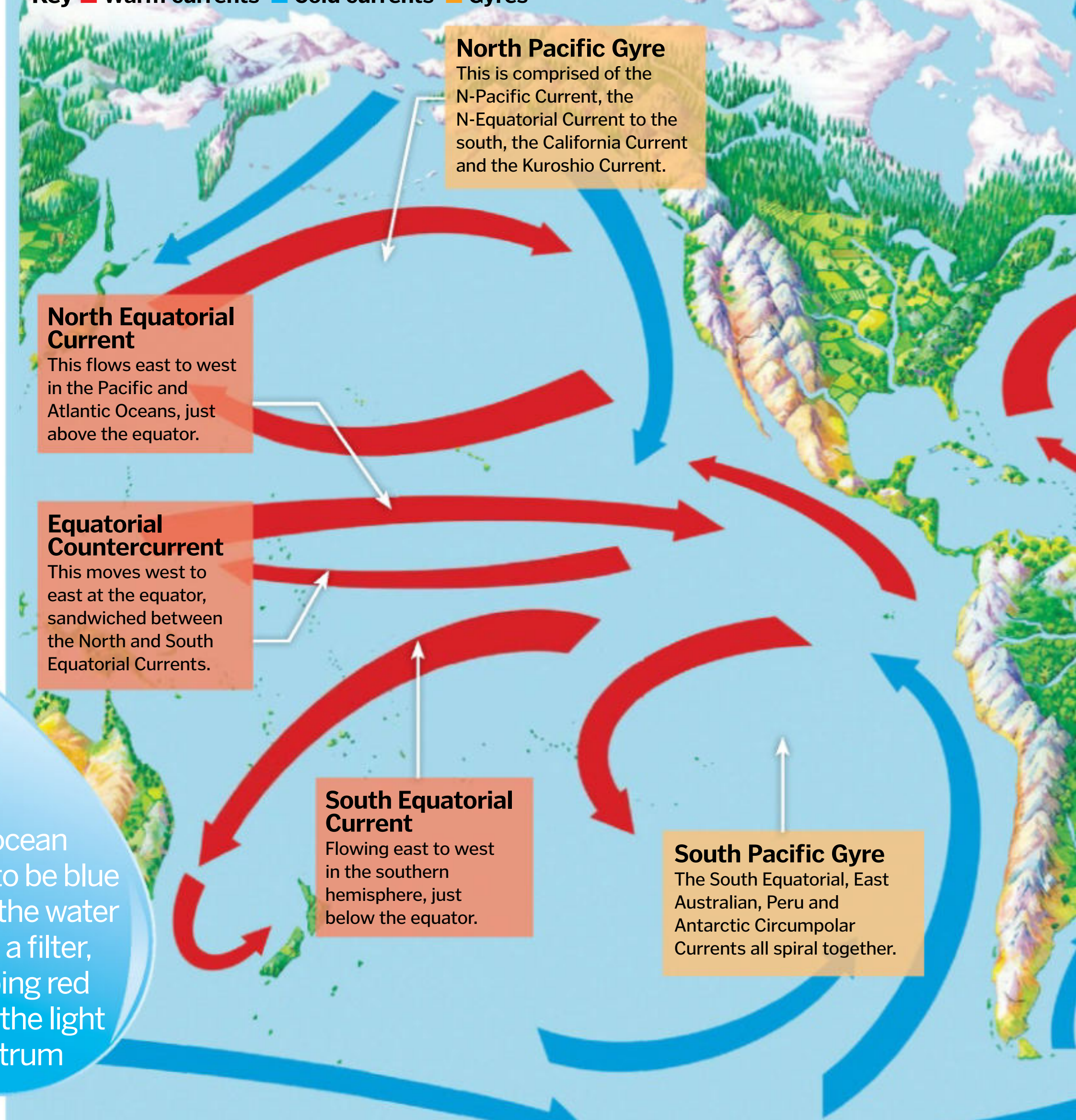
The circulation of water transports oxygen and nutrients around the oceans. It also carries vast amounts of moisture and heat around our planet, which affects our climate. Without the currents to regulate the uneven distribution of solar radiation that reaches Earth's surface, the climate would be far more extreme.

One major climactic process produced by ocean current activity is El Niño – the appearance of warm surface water off the coast of Peru every few years in December. This warming process is actually a by-product of a much larger ocean process known as the El Niño Southern

> The ocean appears to be blue because the water acts as a filter, absorbing red parts of the light spectrum

Map of ocean currents

How do the oceans move around the Earth?



Evolution of the oceans

Ocean origins

By 650 million years ago (MYA) the Earth's crust had broken into plates, moving over molten rock and pushing up against one another, protruding from the water that covered the planet.

Making new seas

By 306 MYA, the largest chunks of land had begun to break up and move away from one another. Magma from within the Earth's core bubbled up and hardened to create ocean basins.

Emerging continents

152 MYA saw the landmasses move farther apart to form two distinct areas – Laurasia and Gondwanaland. Two main oceans were evident at this stage: the Pacific and the Tethys.

Familiar geography

By 50.2 MYA the oceans had begun to resemble the modern map. By this point both Laurasia and Gondwanaland had split into smaller continental plates far more familiar today.

1. LARGEST
Jupiter's Europa
If Europa's subsurface ocean is proven to exist, it could contain twice the amount of water found on our planet.

2. HOTTEST
Jupiter's Io
Scientists now believe that Io has an ocean of molten rock beneath its crust that feeds the moon's endless violent volcanic eruptions.

3. FAKEST
Earth's Moon
The Mare Tranquillitatis, or Sea of Tranquillity, isn't actually a sea at all. This lunar mare is found in the Tranquillity basin on Earth's satellite.

DID YOU KNOW? *If Earth were slightly closer to the Sun, the oceans would evaporate. If slightly farther away, they would freeze*

East Greenland Current
Flowing along the edge of Greenland this transports colder water in a southern direction from the Arctic Ocean.

Cold water
Cold water from the poles travels to equatorial regions, where it is heated and the cycle repeats.

Warm water
Warm currents dissipate their heat as they travel across the sea, making nearby countries warmer and wetter.

Gulf Stream
One of the fastest surface currents, the Gulf Stream carries warm water across the North Atlantic.

Indian Ocean Gyre
Water from the W-Australian Current and S-Equatorial Current whirl around the centre of this ocean.

North Atlantic Gyre
Made up of warm water from the N-Equatorial Current and the Gulf Stream, with cooler water from the N-Atlantic Current.

Gyres
Large rotations of currents driven by surface winds. They flow clockwise in the northern hemisphere and anticlockwise in the southern hemisphere.

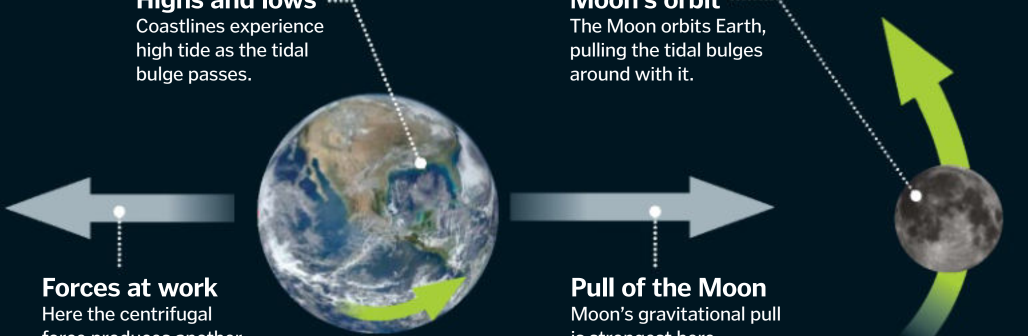
East Australian Current
Moves warm water in an anticlockwise motion down the east coast of Australia.

South-Atlantic Gyre
Comprised of the S-Equatorial Current, Brazil Current and the Benguela Current in rotation.

Antarctic Circumpolar Current
This is the only current that flows around the globe.

How do the tides work?

Tides are long-period waves that move through the seas, primarily due to the gravitational pull of our Moon and Sun. The Moon's pull drags water in the oceans towards it, producing a tidal bulge. On the side of Earth facing away from the Moon, the centrifugal force of the Moon and Earth rotating about each other produces another tidal bulge. As the Moon orbits the Earth, the two tidal bulges track around the Earth relative to the Moon's strongest gravitational pull. This results in the daily high and low tides we see on our coasts.



Highs and lows
Coastlines experience high tide as the tidal bulge passes.

Moon's orbit
The Moon orbits Earth, pulling the tidal bulges around with it.

Forces at work
Here the centrifugal force produces another tidal bulge.

Pull of the Moon
Moon's gravitational pull is strongest here, producing a tidal bulge.

"The crushing depths of the abyssopelagic zone are found at the very bottom of the ocean basins"

Oscillation (ENSO), which is a natural climate phenomenon concerning oceans and atmospheres, the effects of which can have widespread implications for global weather.

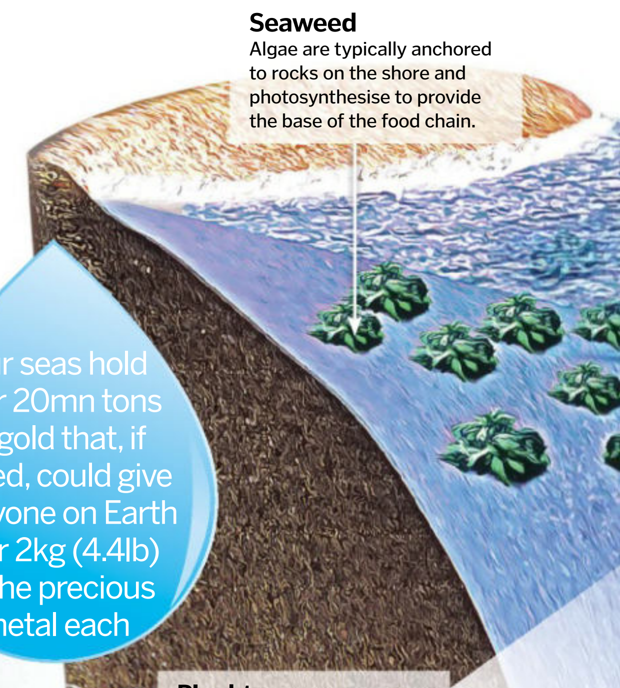
The Sun-lit surface of the oceans is known as the epipelagic zone, where as on land photosynthesis forms the basis of the food chain. Plankton blooms take advantage of the light and provide the dinner of choice for many marine species. The smaller fish provide food for larger hunters and so the transfer of energy is passed down the oceans' layers.

In the mesopelagic zone light gradually tails off to twilight and photosynthesis is no longer possible. Beneath this is the blackness of the bathypelagic zone, some 1,000 metres (3,300 feet) below the surface. Finally, deeper still, the crushing depths of the abyssopelagic zone are found at the very bottom of the ocean basins.

The waters of ocean trenches are known as the hadalpelagic zone – an unforgiving realm of inky darkness, freezing waters and crippling pressure, yet a surprising array of life survives there against the odds. At the deepest point – the Challenger Deep in the Mariana Trench – the pressure is more than 1.2 tons per square centimetre (7.7 tons per square inch), which is the equivalent of one person trying to hold up 50 jumbo jets!

Due to the tectonic activity of these regions, ocean trenches and areas around them are punctuated with large vent chimneys that spew out chemical-rich water from within Earth's core. Vent communities are teeming with unique species, thanks to the presence of bacteria that use chemosynthesis to form the

Our seas hold over 20mn tons of gold that, if mined, could give everyone on Earth over 2kg (4.4lb) of the precious metal each

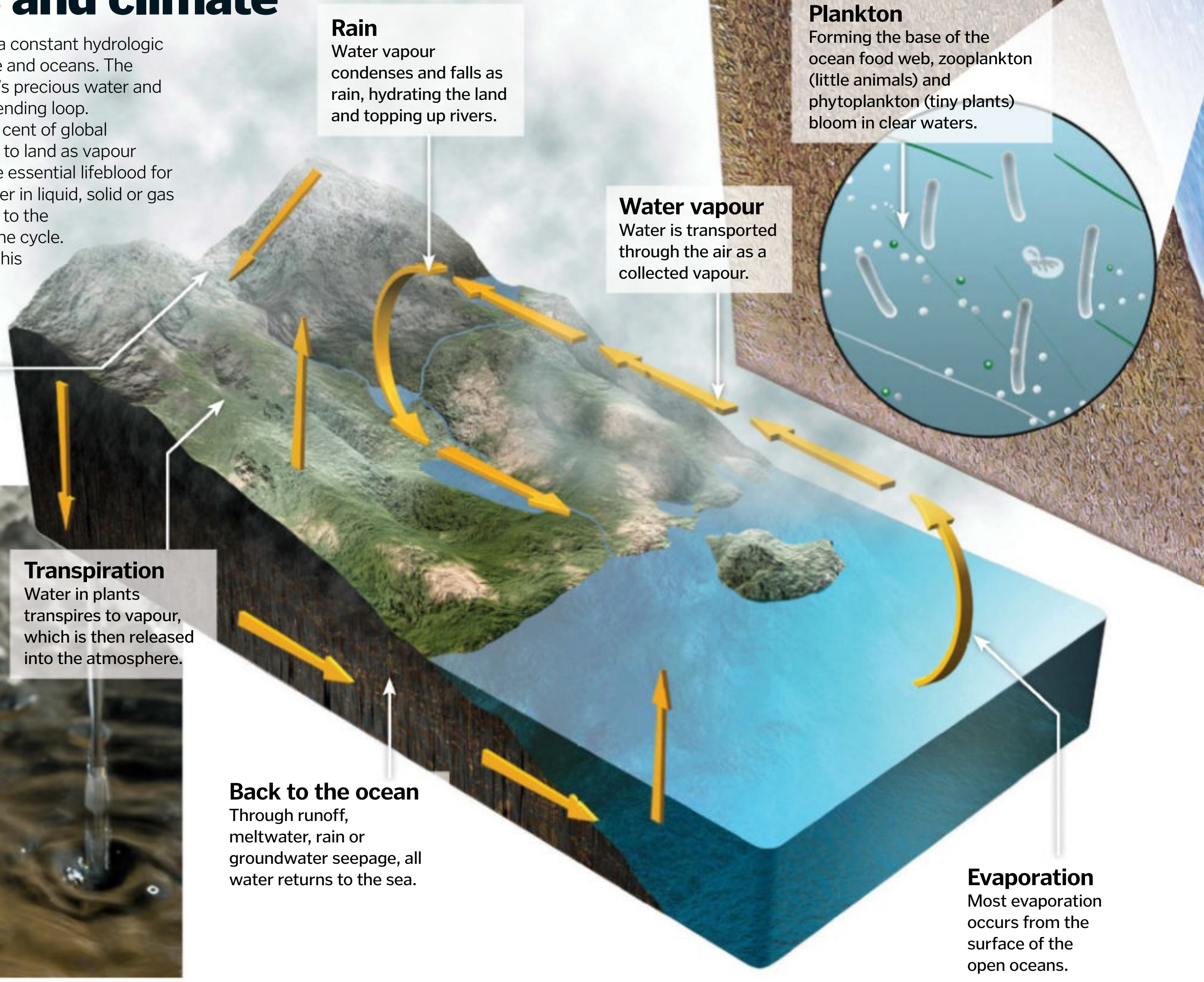


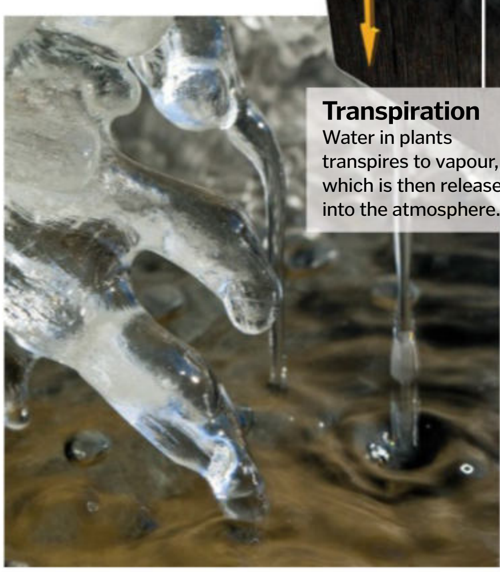
The oceans and climate

The water on our planet exists in a constant hydrologic cycle linking the land, atmosphere and oceans. The oceans store 97 per cent of Earth's precious water and play an essential role in its never-ending loop.

The oceans account for 86 per cent of global evaporation, which is transported to land as vapour where it falls as rain, providing the essential lifeblood for all beings on land. This water, either in liquid, solid or gas form, will then make its way back to the ocean via rivers etc to complete the cycle.

The transfer of water through this system also transfers energy and heat, which is closely linked to changes in our climate.





STRANGE BUT TRUE
COLD HARD FACT

What is a cold seep?

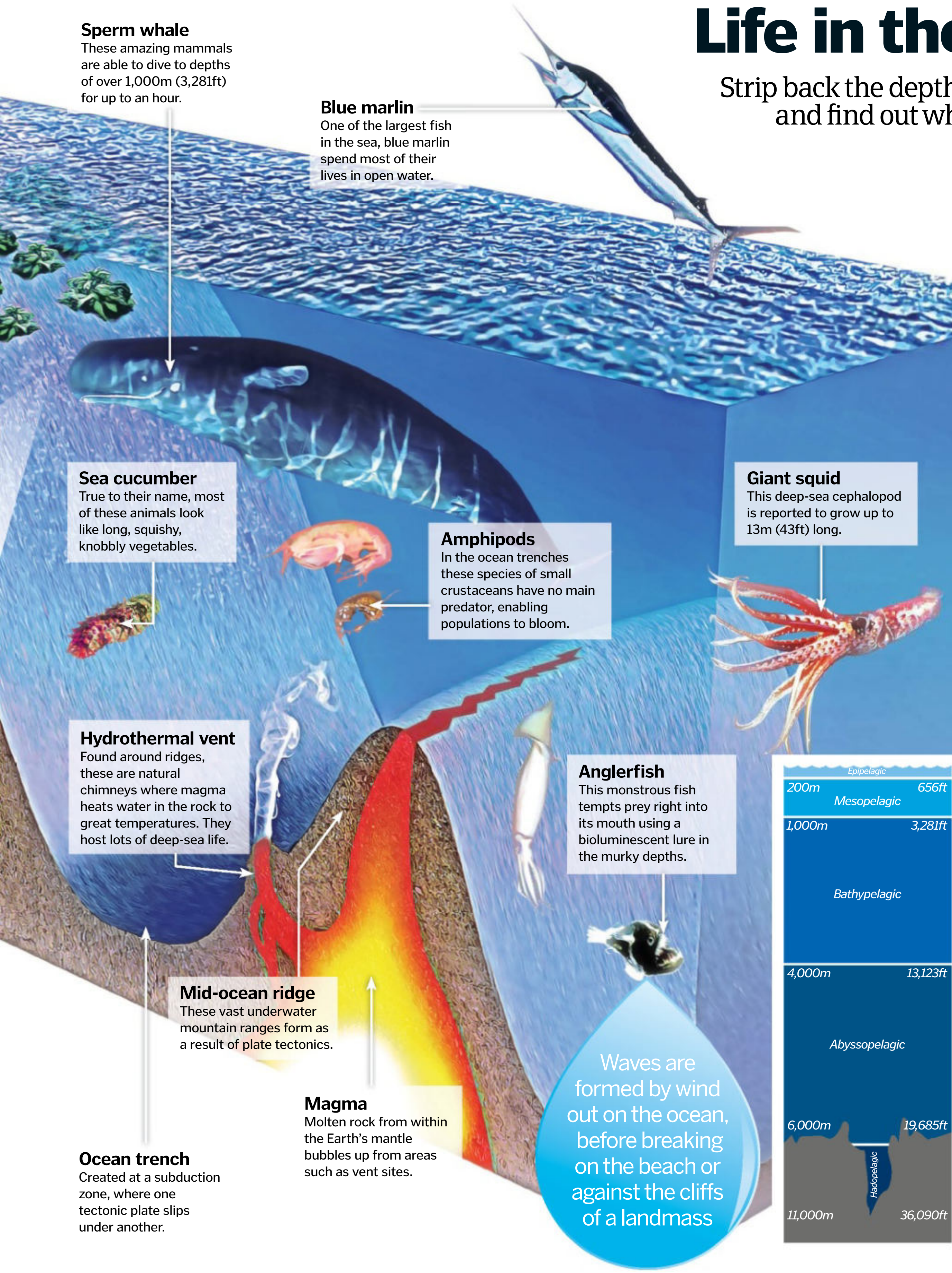
A An underwater brine lake
B An underwater gas vent
C A type of deep-sea fish flu

Answer:
Cold seeps are depressions in the seafloor filled with incredibly salty water, resembling underwater lakes. They can sustain a huge array of deep-sea life that relies on the chemical breakdown of hydrogen sulphide, or methane, as a primary energy source.

DID YOU KNOW? *El Niño is Spanish for Christ child, named by fishermen who noticed it occurred around Christmas*

Life in the deep

Strip back the depths layer by layer and find out what lies beneath



Sperm whale
These amazing mammals are able to dive to depths of over 1,000m (3,281ft) for up to an hour.

Blue marlin
One of the largest fish in the sea, blue marlin spend most of their lives in open water.

Sea cucumber
True to their name, most of these animals look like long, squishy, knobbly vegetables.

Amphipods
In the ocean trenches these species of small crustaceans have no main predator, enabling populations to bloom.

Giant squid
This deep-sea cephalopod is reported to grow up to 13m (43ft) long.

Hydrothermal vent
Found around ridges, these are natural chimneys where magma heats water in the rock to great temperatures. They host lots of deep-sea life.

Anglerfish
This monstrous fish tempts prey right into its mouth using a bioluminescent lure in the murky depths.

Mid-ocean ridge
These vast underwater mountain ranges form as a result of plate tectonics.

Magma
Molten rock from within the Earth's mantle bubbles up from areas such as vent sites.

Ocean trench
Created at a subduction zone, where one tectonic plate slips under another.

Waves are formed by wind out on the ocean, before breaking on the beach or against the cliffs of a landmass

Epipelagic
200m
656ft
Mesopelagic
1,000m
3,281ft
Bathypelagic
4,000m
13,123ft
Abyssopelagic
6,000m
19,685ft
Hadopelagic
11,000m
36,090ft

0-5m (0-16ft)
Intertidal zone
Here the ocean meets the land. Waves batter the shore, but then disappear with the tide to leave the beach baking in the Sun.

0-200m (0-656ft)
Epipelagic zone
Known as the sunlight zone, light is plentiful here, making it the warmest layer of all Earth's oceans.

200-1,000m (656-3,281ft)
Mesopelagic zone
Often referred to as the twilight zone, this represents the farthest reaches of sunlight. Not enough light makes it through to enable photosynthesis though.

1,000-4,000m (3,281-13,123ft)
Bathypelagic zone
Known as the midnight zone because the light is nonexistent. It's inky black from here on in, and temperatures stay at around 4°C (39°F)

4,000-6,000m (13,123-19,685ft)
Abyssopelagic zone
These are the waters of the abyss, or the very bottom of the ocean basin. The animal life here has to endure crushing pressure and extreme cold.

6,000-11,000m (19,685-36,089ft)
Hadopelagic zone
The hadal zone refers to the deepest parts of our oceans and generally occurs in deep-sea trenches like the Mariana Trench. It is one of the least documented environments on Earth.

"With so much technology at our fingertips, it's impossible not to wonder what else is out there"

basis of the food chain. The bacteria use hydrogen sulphide in the vent water, along with oxygen and carbon dioxide, to create sugars, providing sustenance for smaller vent-dwellers. This gets transferred up the food web and soon the vent is jumping with biodiversity.

It's said we know more about outer space than we do about our oceans on Earth. It's not hard to see why, when the average depth of the oceans is more than 3.7 kilometres (2.3 miles). As well as sending ROVs (remotely operated vehicles) and subs down to investigate the depths, oceanographers have developed many different methods for sampling this watery world.

For instance, the seafloor can be mapped using sound waves, which travel at 1,500 metres (4,921 feet) per second in water. Echo sounders, backscatter and sound velocity profilers can all be used to accurately detect the depth, shape and composition of the seabed.

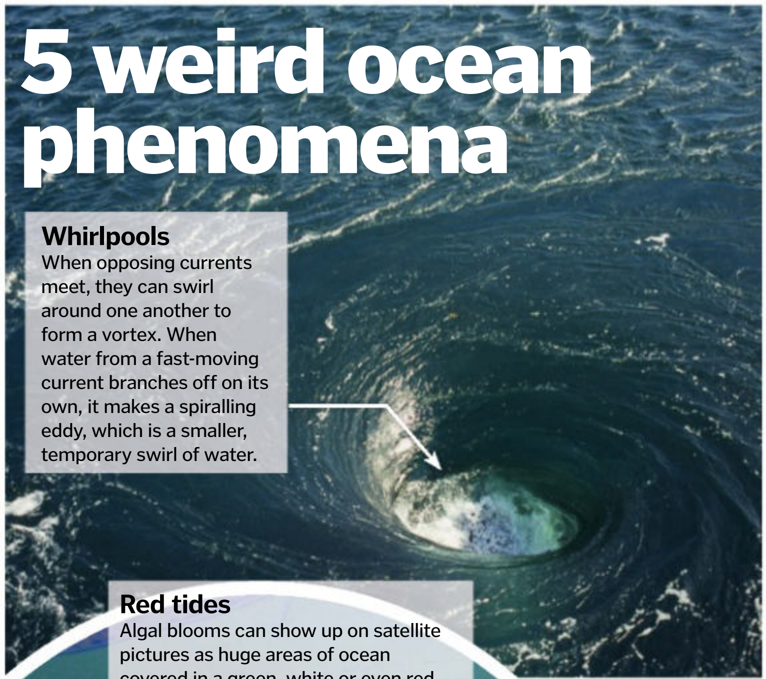
Other methods for sampling the ocean include salinity and temperature profiling, while lowering instruments to depths and then returning them to the surface can build up a more detailed picture. Samples can also be taken using dredges, core samples and trawls to collect organic matter.

Satellites in orbit are equipped with various sensors to relay many different ocean variables back to Earth for analysis. For example, sea surface temperature, air-sea interactions, ocean waves, currents and sea-ice patterns can all be viewed and monitored from afar. There are also monitoring systems that use buoys moored in the seas that constantly measure ocean movements. This kind of technology is especially useful for applications such as advance warnings for tsunamis.

There's so much left to discover about our oceans and with so much technology at our fingertips, it's impossible not to wonder at what else is out there. How many more breakthroughs are lurking just beneath the waves, waiting to be found?

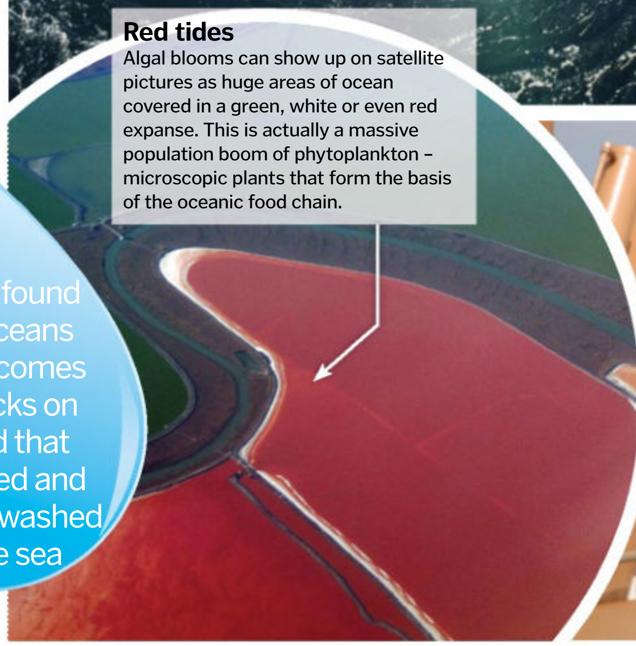
The salt found in the oceans actually comes from rocks on the land that are eroded and gradually washed into the sea

5 weird ocean phenomena



Whirlpools

When opposing currents meet, they can swirl around one another to form a vortex. When water from a fast-moving current branches off on its own, it makes a spiralling eddy, which is a smaller, temporary swirl of water.



Red tides

Algal blooms can show up on satellite pictures as huge areas of ocean covered in a green, white or even red expanse. This is actually a massive population boom of phytoplankton – microscopic plants that form the basis of the oceanic food chain.

Battle of the oceans

YOUNGEST

Atlantic

Within the Atlantic Ocean is the Mid-Atlantic Ridge – the longest mountain range on Earth. It spreads right down the middle of the ocean, all the way from Iceland to Antarctica.

LARGEST

Pacific

The mighty Pacific Ocean occupies a third of the Earth's surface. The Ring of Fire, an area of increased seismic activity with many volcanoes, borders it and it's host to the deepest trench.

SMALLEST

Arctic

At the very top of the world, the Arctic Ocean surrounds the North Pole and covers 14mn km² (5.4mn mi²). This ocean is almost completely covered with sea-ice every winter.

WARMEST

Indian

Thanks to the Indo-Pacific warm pool (a body of warm water stretching partway around the globe near the equator), the Indian Ocean has some of the warmest sea surface temperatures in the world.

5 TOP FACTS
TAMING OCEANS

Tidal barriers
1 These huge barriers are erected across estuaries to prevent flooding. They usually consist of massive gates that are raised to block the river and hold back the high tide.

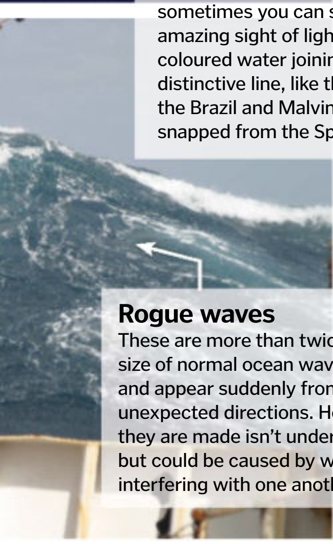
Jetties
2 Built to limit sediment deposition at the mouth of a harbour, jetties work to channel and control the flow of water running from an inlet or estuary.

Groynes
3 Groynes are built at right-angles on beaches, reaching out into the sea to trap sand and promote buildup so the sea can't wash away the beach so easily.

Breakwaters
4 Built parallel to the shoreline, breakwaters are designed to absorb the energy of pounding waves and deflect waves out to sea, protecting the shoreline behind it.

Beach nourishment
5 This technique introduces sand to a beach from other sources, such as nearby quarries. It expands the natural beach, which in turn protects the shoreline.

DID YOU KNOW? A tsunami travelling across the ocean is capable of reaching speeds of 600km/h (373mph)



Brinicles
These are long fingers of ice that form beneath the sea-ice. When sea-ice freezes, the salt from the seawater is excluded from the crystals. This leaks out through cracks in the ice, and its osmotic properties draw water to it. The brine is super-cooled, so the water freezes and a brinicle is formed.

Convergence zones
Where two ocean currents come together with very different density profiles or temperatures, sometimes you can see an amazing sight of lighter and darker coloured water joining, often in a distinctive line, like this picture of the Brazil and Malvinas Currents snapped from the Space Shuttle.

Rogue waves
These are more than twice the size of normal ocean waves and appear suddenly from unexpected directions. How they are made isn't understood, but could be caused by waves interfering with one another.

Earth's oceans in numbers

450
Degrees in Celsius of the hottest hydrothermal vent found in the Cayman Trough

5,900km
Length of the Peru-Chile trench – the longest ocean trench

16
metres is the highest recorded tide in the Bay of Fundy

90
per cent of all Earth's volcanic activity occurs in the oceans

65,000km
Length of the longest underwater mountain range known as the mid-ocean ridge

170mn
Area in square kilometres of the biggest ocean, the Pacific. It covers 30 per cent of the planet

10,994km
The deepest point of all the world's oceans, found at the Challenger Deep in the Pacific

FIERCEST

Southern
Unbroken by any continental landmass, winds are free to rage around the Southern Ocean that surrounds Antarctica, resulting in many fierce storms with terrifying waves.

Which animal is the tarantula's arch-nemesis?

A Hawk B Monkey C Snake

Answer:
These giant spiders don't have many predators to fear, but at the top of the list has to be the tarantula hawk – not actually a bird but a type of parasitic wasp. They sneak into the spider's burrow, paralyse them and lay an egg on their abdomen before sealing them in. When it hatches the larvae eats the tarantula alive!

DID YOU KNOW? *The biggest tarantula ever discovered had a leg span of 28cm (11in) – enough to cover a dinner plate!*

All about tarantulas

Unravelling the secrets of the world's largest spiders

They may be the ultimate nightmare for arachnophobes, but tarantulas are incredible creatures once you look beyond their fearsome exterior. With some 900 species spread throughout the world, from tropical rainforest to arid deserts, their ability to adapt is a feat that deserves respect.

Webs are impractical for a spider this big, but they still make use of silk in their homes. Many tarantulas dig silk-lined burrows to shore up the walls and with 'tripwires' extending from the entrance to signal prey and potential mates. Others live in trees, in tubes made of silk or in gaps in the bark, while some species have no fixed abode, preferring a nomadic lifestyle.

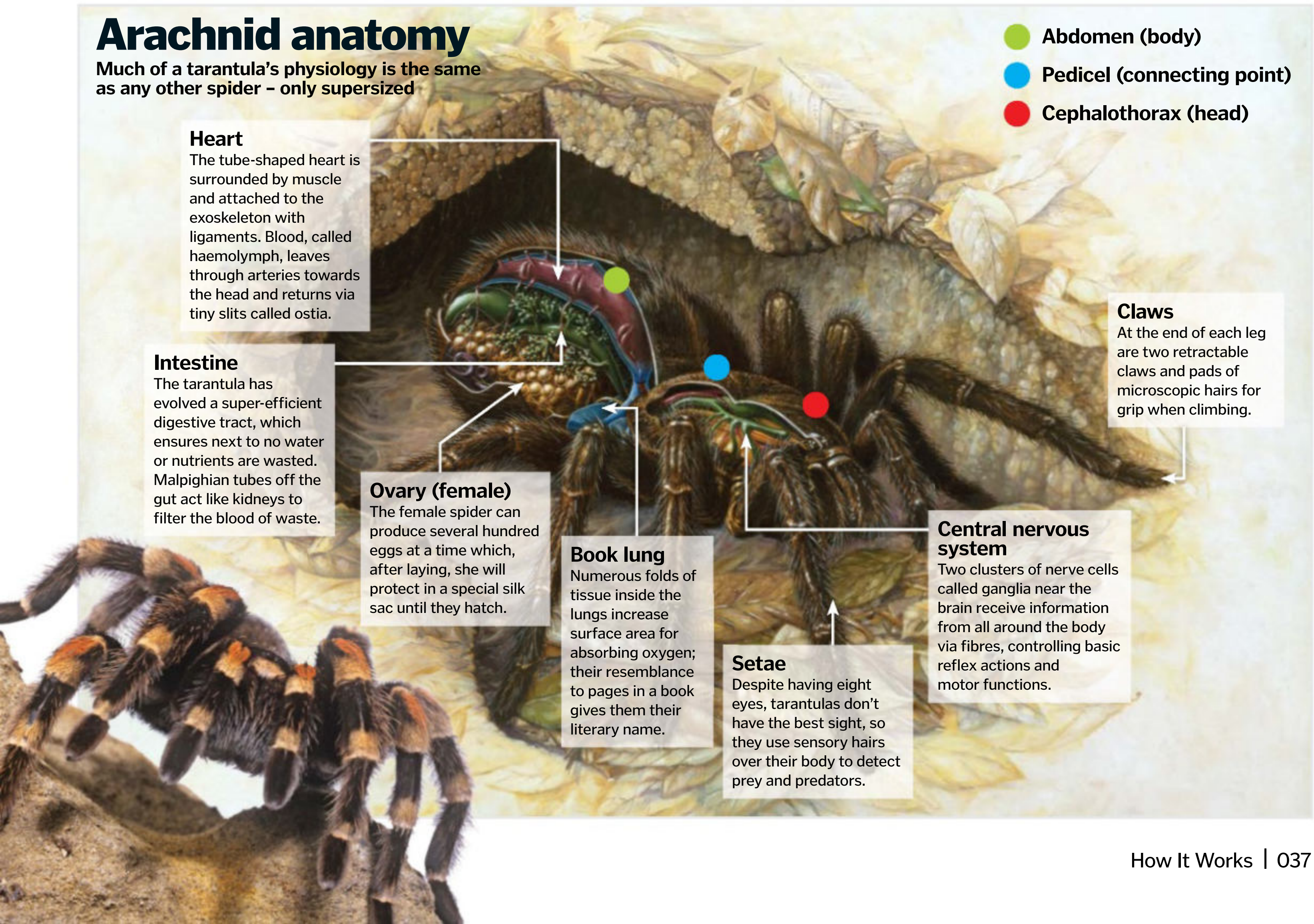
Generally resting during the day, tarantulas use the cover of darkness to their advantage to ambush prey. Their typical quarry is insects, eg crickets, but larger species are capable of taking down small rodents, lizards and even baby birds. Once they have pounced, articulated fangs up to 2.5 centimetres (one inch) long deliver a lethal dose of venom before injecting digestive juices to start breaking down their meal for a liquid lunch. Surprisingly, the venom is thought to be weaker than a bee's sting so bites to humans are fairly harmless, if painful.

They may be the planet's biggest spiders, but they too have their enemies who'd like to make dinner of them. As a result, tarantulas have developed some cunning defence strategies to deter predators before having to use their fangs. In the first instance, the spider will rear up on its hind legs to make itself look bigger and to expose its fangs as a warning. If this doesn't work, New World species have another trick up their sleeve – or at least on their abdomen – in the form of urticating bristles. With quick leg movements over its abdomen it dislodges a cloud of barbed microhairs that can irritate an assailant's eyes and skin.

Even if they do get injured during an attack, all is not lost. Like all arthropods, tarantulas have to shed their outer skeleton in order to grow – typically about once a year – in a process known as moulting. As well as replacing the old suit of hair-lined armour and certain organs, over the course of two or three moults entire limbs can be regenerated.

Arachnid anatomy

Much of a tarantula's physiology is the same as any other spider – only supersized



Heart
The tube-shaped heart is surrounded by muscle and attached to the exoskeleton with ligaments. Blood, called haemolymph, leaves through arteries towards the head and returns via tiny slits called ostia.

Intestine
The tarantula has evolved a super-efficient digestive tract, which ensures next to no water or nutrients are wasted. Malpighian tubes off the gut act like kidneys to filter the blood of waste.

Ovary (female)
The female spider can produce several hundred eggs at a time which, after laying, she will protect in a special silk sac until they hatch.

Book lung
Numerous folds of tissue inside the lungs increase surface area for absorbing oxygen; their resemblance to pages in a book gives them their literary name.

Setae
Despite having eight eyes, tarantulas don't have the best sight, so they use sensory hairs over their body to detect prey and predators.

Central nervous system
Two clusters of nerve cells called ganglia near the brain receive information from all around the body via fibres, controlling basic reflex actions and motor functions.

Claws
At the end of each leg are two retractable claws and pads of microscopic hairs for grip when climbing.

> "Darwin realised the birds that had successfully adapted their beak were more likely to survive"

Why do birds have beaks?

Learn how birds' bills have adapted to fill a wide range of ecological niches

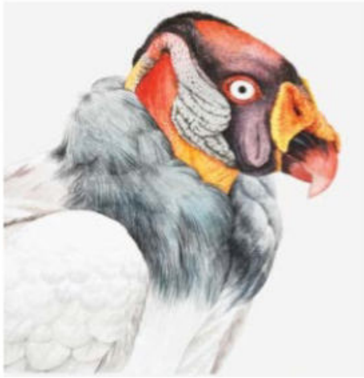
Beaks appeared very early on in the evolution of land-based creatures. Dinosaurs like the Segnosaurus developed a snout encased in keratin, a protein made up of keratinocytes that dry and harden when on the surface of the body. This made probing termite nests much easier for the Segnosaurus.

This evolutionary advantage allowed beaked dinosaurs to thrive, a trait passed down to birds and turtles. Beaks also played a key role in the understanding of evolution. In the 19th century Charles Darwin noticed that finch beaks on the Galápagos Islands varied greatly.

Birds with small, stout beaks preferred seeds found on the ground, while longer, sharper beaks were more suited to catching insects or extracting seeds from cacti. Darwin realised the birds that had successfully adapted their beak were more likely to survive.

This variation in beak size and shape is due to the presence of calmodulin, a calcium-based molecule that increases the length of the beak, while levels of bone morphogenic protein 4 (BMP4) determine its width and depth.

Pelican – fish
Pelicans are able to scoop up whole fish in a massive gulp using their elongated bills and store them for later consumption in their elastic throat pouch.



Vulture – carrion
The vulture's short, hooked beak is perfect for tearing away strips of flesh from a carcass, so the beak is key to making them such an excellent scavenger.

Finch – seeds/insects
The finch has a short, stubby beak, but it can vary in length, so different species are suited to a range of environments. Some even use tools like sticks to spear grubs.

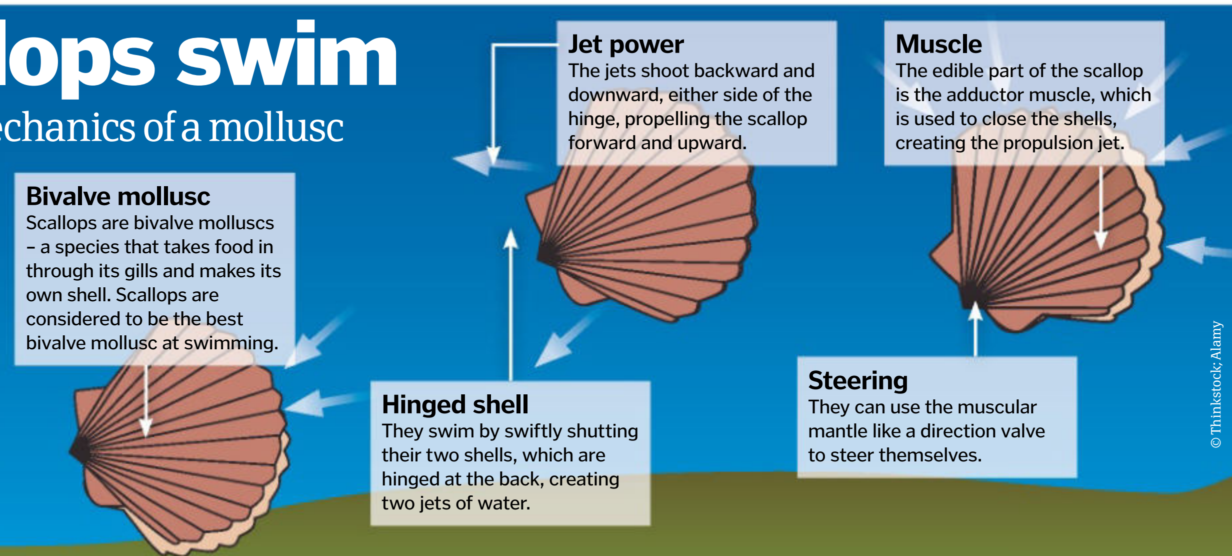
Kingfisher – fish/insects
The lightweight kingfisher's thin, long beak is perfectly suited for snatching fish and insects out of the water and the air, meaning it can eat on the wing.

Toucan – berries
This South American bird has the largest beak for any other bird of its size. It uses it to pick berries, but also for thermal regulation, a bit like an elephant's ears.

Hummingbird – nectar
The sword-billed hummingbird's bill can be even longer than its body and is perfect for reaching the nectar in long, tubular flowers, while it hovers before them.

How scallops swim

Revealing the mechanics of a mollusc in motion



1. TALLEST

Norfolk Island tree fern
Tree ferns like this Pacific species can grow to over 20m (66ft) tall. Their trunks are made up from annual dead leaf bases.

2. SMALLEST

Water fern
Water ferns (eg Azolla species) have stems shorter than 5cm (2in) long and tiny fronds. You'll find them floating on ponds and in ditches.

3. COMMONEST

Bracken
Bracken is a widespread fern, found in every continent on Earth except Antarctica. It is so invasive that it can spread to take over entire hillsides.

DID YOU KNOW? *The silver fern is a national symbol of New Zealand; the Maori once used their silvery glow to navigate at night*

The life cycle of ferns

How this ancient group of plants has survived for millions of years

About 450 million years ago, the first land plants emerged from the water. They were simple green flaps, a bit like modern liverworts. Later, slightly more advanced moss-like plants appeared, and these evolved into the more complex form of ferns, horsetails and club mosses. 300 million years ago, ferns and their allies dominated a world that was much wetter than today. As a result, they only needed a simple system to move water to their stems and leaves.

These ancient plants had a two-stage life cycle. The mosses and liverworts that we typically find on rocks and in damp woods are all gametophytes – the sexual stage in the moss's life cycle, which produce the equivalent of eggs and sperm, called gametes. In wet weather, the male gametes swim over the moist surface of moss leaves to fertilise the eggs. These then develop into a stalk topped by a cap. This second stage, which relies entirely on the gametophyte for nourishment, is called the sporophyte, because it produces spores like simple seeds. These are shaken from pores in the cap and blown to a new site, where they grow into new gametophytes, but these can only survive in wet conditions.

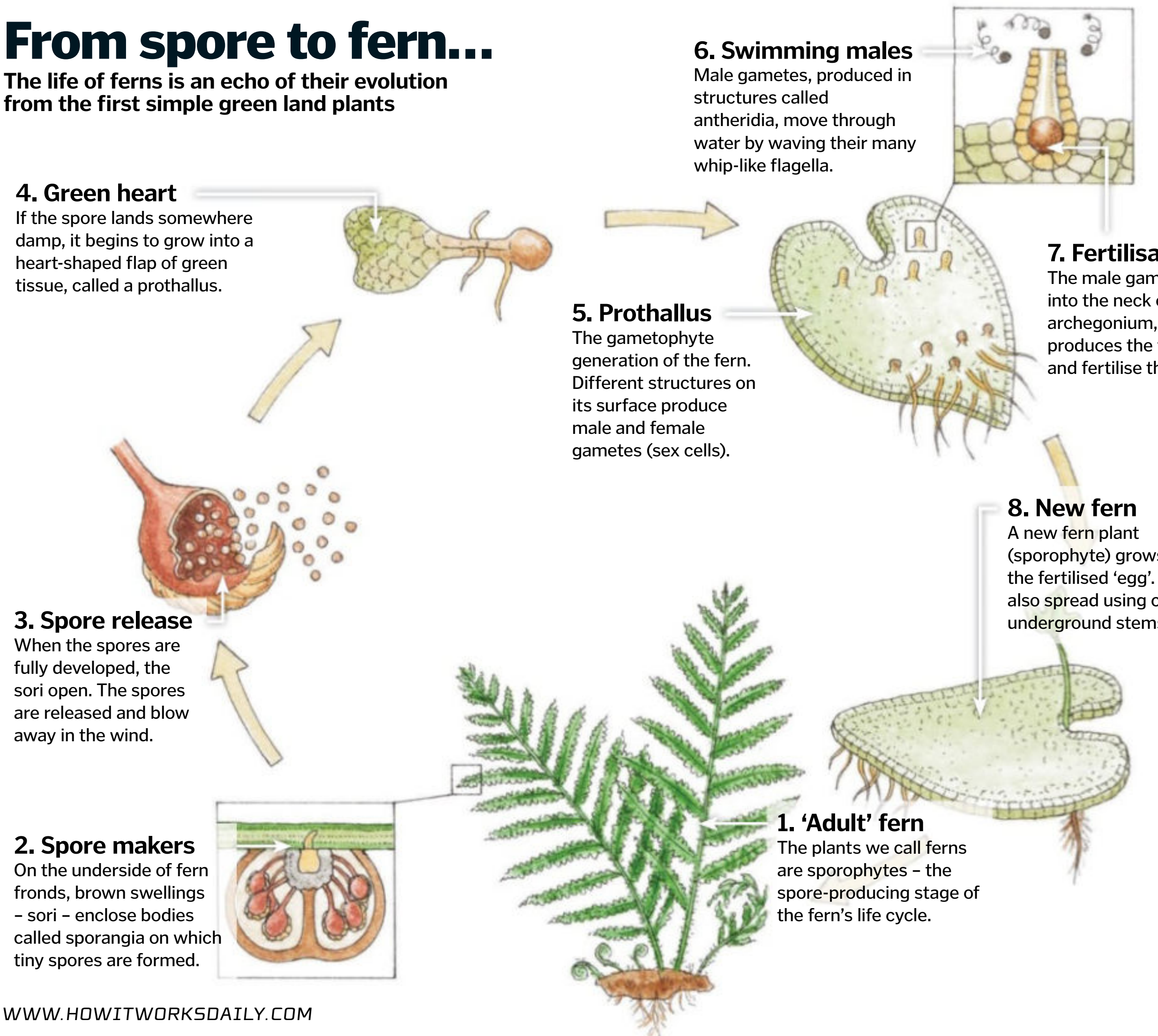
Ferns have evolved so that the sporophyte has become the dominant stage in their life. Ferns, horsetails and club mosses are all sporophytes that live freely, even in quite dry conditions. The spores they release develop first into gametophytes and these reproduce sexually to create the next generation.

Ferns, fossils and fuels

300 million years ago, ferns and their relations formed the main vegetation of our planet. Flowering plants did not appear for another 175 million or so years. In this Carboniferous period, the continental plates carrying North America and Europe were situated close to the equator in wet, tropical conditions. In the steamy swamps, club mosses over 30 metres (98 feet) tall grew in dense forests. The remains of these club mosses and horsetails formed much of today's coal, and many impressions of fern fronds are found as fossils in ancient rocks.

From spore to fern…

The life of ferns is an echo of their evolution from the first simple green land plants



"Caves without any direct contact with the outside world can still experience climatic variations"

Cave weather

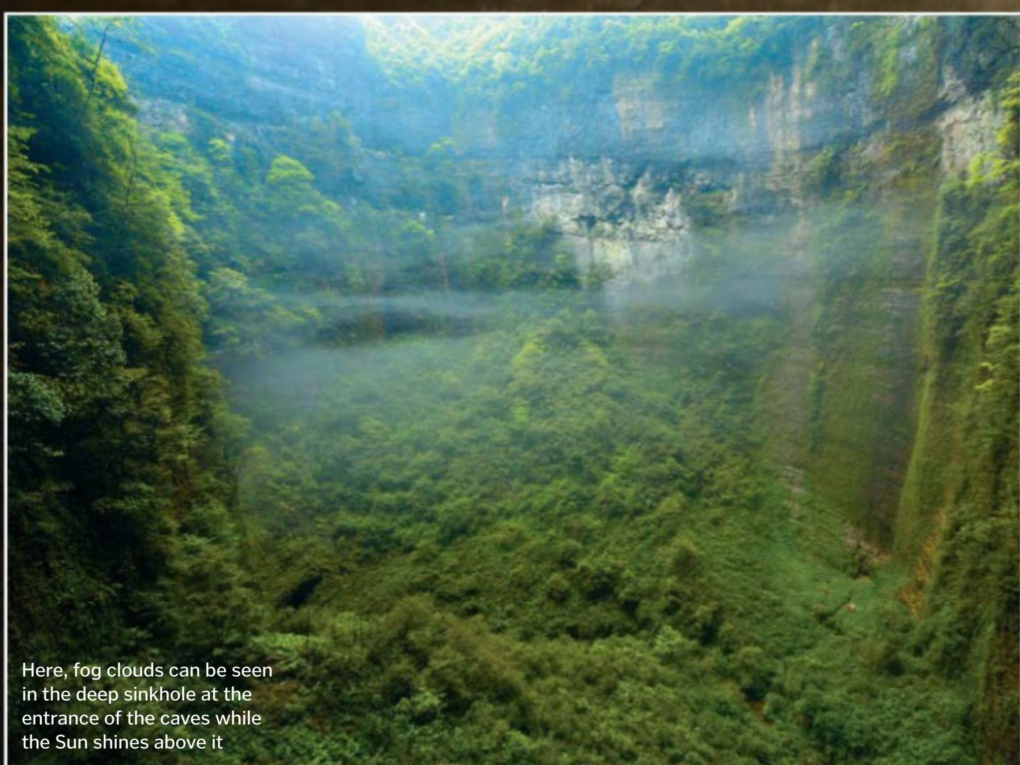
Explore one of China's most stunning cave systems to learn why it has developed its own microclimate

Cut off from the Sun, rain and wind that we experience on the surface, you might assume meteorological conditions in caves never change. However, the reality is that their climates do vary significantly – not only from location to location, but within individual caves over time. Indeed, some examples, like the Er Wang Dong cave system in Chongqing Province, China (main picture), even host their own weather. Ultimately this is because very few caves are 100 per cent cut off from their surroundings.

In the case of Er Wang Dong, it all comes down to an imbalance in the local topology. There are several tunnels around the cave system's perimeter where wind can blow in. Once trapped underground air from outside gains moisture, pooling into huge chambers like Cloud Ladder Hall – the second-biggest natural cavern in the world with a volume of 6 million cubic metres (211.9 million cubic feet). Once in an open chamber this humid air rises.

While there are numerous entrances into this subterranean complex, exits are few and far between. In Cloud Ladder Hall's case, it's a hole in the roof some 250 metres (820 feet) above the floor, leading to a bottleneck effect. As the damp air hits a cooler band near the exit, tiny water droplets condense out to create wispy mist and fog. In other chambers plants and underground waterways can also contribute to underground weather.

Even caves without any direct contact with the outside world can still experience climatic variations, as they are subject to fluctuations in atmospheric pressure and geothermal activity, where the heat from Earth's core emanates through the rocky floor. However, in such caves, changes are more evenly distributed so take place over longer time frames.



Here, fog clouds can be seen in the deep sinkhole at the entrance of the caves while the Sun shines above it

Sizing up Cloud Ladder Hall

Area 7 football pitches

Height 2.5 Statues of Liberty

Volume 5 Wembley Stadiums

10mn m³

BIGGEST UNDERGROUND CHAMBER

The Cloud Ladder Hall is only beaten by the Sarawak Chamber in Borneo in scale. Sarawak is estimated to have almost double the volume of the Chinese cavern, in the range of 10mn m^3 (353.1mn ft^3).

DID YOU KNOW? *Although previously mined, the Er Wang Dong cave system was only properly explored for the first time in 2013*

© Robbie Shone

Mega telescopes

They're our biggest eyes on the sky, but how are these huge mirrors and dishes transforming our view of the universe?

When it comes to astronomy, bigger is always better. A new generation of giant telescopes is pushing the limits of engineering to answer some of our biggest questions about the universe. New technology means that mountain-top monsters like Hawaii's Keck Telescopes can compete with the perfect visible-light views of the Hubble Space Telescope, while the next generation of giants will supersede even Hubble. And when it comes to radio waves (radiation whose long wavelengths can reveal the cool gas and dust of an otherwise invisible cosmos), the engineering challenges of projects such as the Atacama Large Millimeter/submillimeter Array (ALMA) are so huge that they can only be attempted on the ground.

Why go big? There are two reasons. A telescope is essentially a tool for gathering incoming photons of light from distant objects, so doubling the diameter of a telescope's light-collecting primary mirror quadruples its 'light grasp'. Its diameter also affects its resolving power – its ability to separate tightly spaced objects and see fine detail. With a 'single-element' mirror or radio telescope, light grasp and resolving power go hand in hand, but there are tricks for improving resolution if you can't build a single giant collecting surface.

A compound eye on the sky

Depending on how you look at it, the largest telescope in the world right now might be the Atacama Large Millimeter/submillimeter Array (ALMA), in Chile's famously dry Atacama Desert. ALMA is actually an array of 66 individual radio telescopes, a dozen of which are dish antennas some seven metres (23 feet) across, while the remainder are 12 metres (39 feet) across. The telescopes combine to observe the sky in radio waves – electromagnetic radiation that has much longer wavelengths than visible light and so needs a much larger telescope to achieve high-resolution images. ALMA's individual antennas, each weighing up to 100 tons, can be relocated across a flat plain over an area of desert some 16 kilometres (ten miles) across, plugging into a network of cables that allows the signals from widely separated telescopes to be combined using a complex technique known as interferometry. Co-ordination between the telescopes requires synchronisation to within a million millionth of a second, but the end result is a radio telescope that produces images at a similar resolution to a single dish around 14 kilometres (8.7 miles) wide – up to an impressive ten times sharper than the visible light images produced by the Hubble Space Telescope.

Great discovery: ALMA
Operational since 2011, the ALMA array has already detected the wreckage from comet collisions in our Solar System and identified cold dust around nearby stars that gives new insight into planet formation. Astronomers are also using it to map the radio waves from some of the universe's most distant galaxies.

1. BIG

The Very Large Telescope

ESO's Chilean complex consists of four 8.2m (26.9ft) telescopes that can be combined to mimic a 130m (427ft) telescope.

2. BIGGER

The Large Binocular Telescope

This Arizona desert giant combines two 8.4m (27.5ft) telescopes for an effective 11.8m (38.7ft) diameter.

3. BIGGEST

Gran Telescopio Canarias

The biggest single-mirror telescope, on La Palma, has a 10.4m (34.1ft) mirror with 36 hexagonal segments.

DID YOU KNOW? *In 1974, the Arecibo scope was used to beam our first deliberate interstellar message toward a star cluster*

Land of the giants

Over the past few decades, Chile's Atacama Desert has become the favoured location for many of the world's largest telescopes. The Atacama runs along a 1,000-kilometre (621-mile) strip of coastal Chile and is the driest hot desert on Earth. A more-or-less permanent high-pressure region over the Pacific Ocean to its west prevents rain reaching it from the sea, while the Andes Mountains to the east cast a similar 'rain shadow'. As a result, the average rainfall is less than one millimetre (0.04 inches) a year, and the atmosphere is virtually free of the water vapour that fogs radio and infrared telescope observations. What's more, the desert lies across an elevated plateau with an average altitude of around five kilometres (3.1 miles), above some 40 per cent of the Earth's atmosphere, ensuring stunningly clear skies on almost every night of the year. Telescopes located here include not just the international ALMA radio array, but also the La Silla and Paranal facilities operated by the European Southern Observatory (ESO), whose instruments include the Very Large Telescope, seen by many as the largest Earth-based optical telescope operating at present. The Cerro Tololo Inter-American Observatory and the construction site for the E-ELT all take advantage of similar conditions in the Atacama region.

7,000m²

THE COMPLETE ARRAY OF 12M (39FT) ALMA TELESCOPES HAS A COLLECTING AREA ABOUT THE SAME SIZE AS A FOOTBALL PITCH

Transporter unit

Two heavy-duty transporters called Otto and Lore are used to relocate individual antennas across the site.

Metal surface

The long wavelengths of the radio waves involved mean that they can be reflected precisely using curved metal rather than mirrors.

Dish design

Each antenna collects radio waves arriving from distant space and reflects them to a receiver apparatus where their amplified effect produces electrical signals.

Hard standing

Stable concrete foundation blocks, linked by cable to the central control centre, are scattered across the plateau.

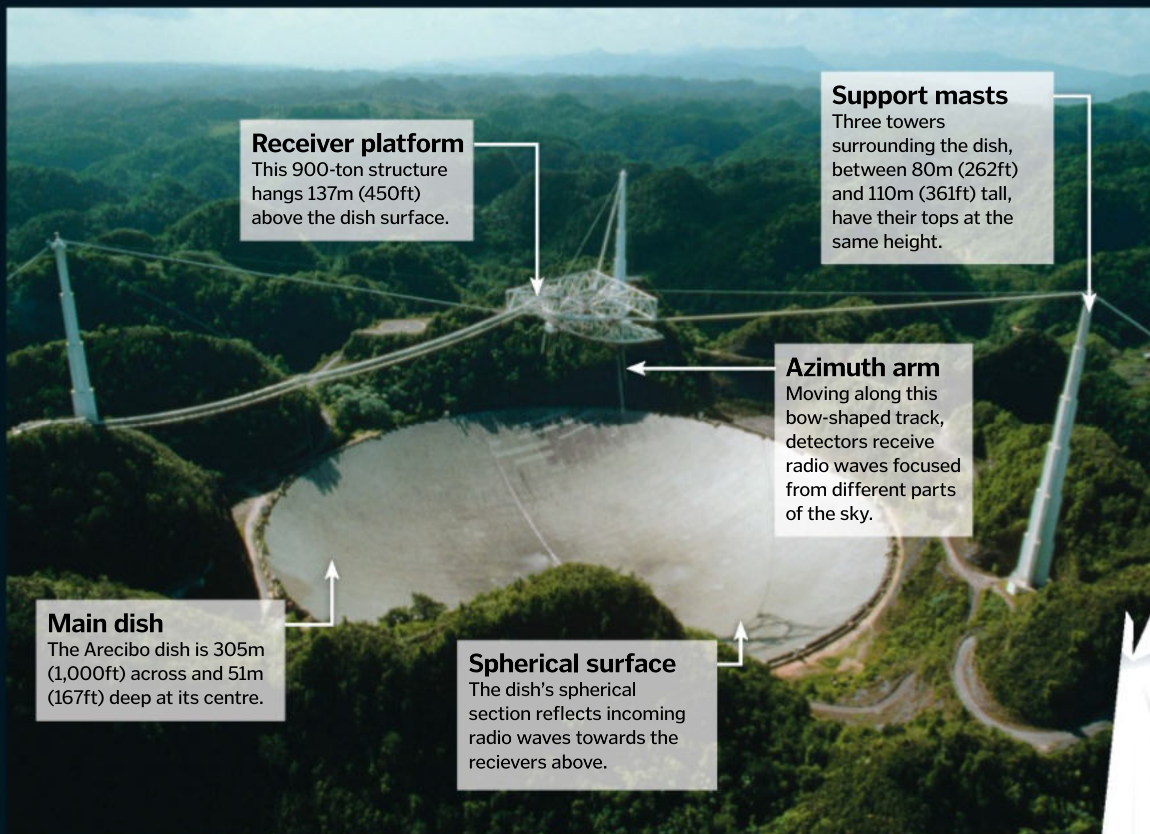
> "Arecibo was originally intended purely as a giant radio antenna for bouncing signals off the ionosphere"

The biggest radio scope

The US National Astronomy and Ionosphere Centre (NAIC) telescope, located at Arecibo on the Caribbean island of Puerto Rico, has become an icon of modern science thanks not only to its spectacular scale, but also to its many appearances in documentaries and movies. With a diameter of 305 metres (1,000 feet), this enormous fixed dish, set within a natural limestone sinkhole, is the largest 'filled dish' telescope in the world (the RATAN-600 radio telescope in the Russian Caucasus is technically even larger, but it consists of a circle of separate, steerable collectors). Arecibo's vast scale means the main dish is not steerable, but a complex detector apparatus suspended overhead can be moved in order to allow detection of radio signals in a 40-degree-wide 'cone of visibility' around the zenith. With the ability to send and receive radio signals, Arecibo was originally intended purely as a giant radio antenna for bouncing signals off the ionosphere region of Earth's upper atmosphere, but amendments built in from the outset have allowed it to be used in many astronomy projects, including the SETI programme, searching for signals from intelligent life beyond our Solar System.

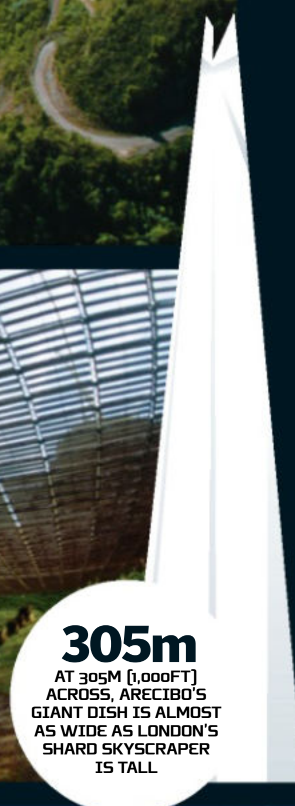
Great discovery: Arecibo

Arecibo's ability to send and receive signals allow it to be used as a planetary radar, sending beams of radio waves towards nearby planets and measuring the signals that returned. In this way, Arecibo was used to make the first maps of cloud-covered Venus, and even to detect the first traces of ice near the poles of Mercury.




The azimuth arm of the Arecibo telescope rotates to direct the reception of signals


The dish's panels are transparent, so plants grow underneath the telescope



Other astronomical giants of the world

We take a close-up look at five more supersized terrestrial telescopes

Twin giants

With primary mirror diameters of 10m (33ft), each made of 36 hexagonal segments, the twin Keck Telescopes marked a breakthrough in telescope technology when they entered service in the 1990s, introducing techniques such as adaptive optics. They can combine to mimic the resolving power of a single 85m (279ft) instrument.

Giant honeycomb

The Giant Magellan Telescope, being built at Las Campanas Observatory in Chile, has a unique design with a primary mirror with seven hexagonal segments, each 8.4m (27.6ft) across. The combined light grasp will match that of a single 22m (72ft) mirror.

RECORD BREAKERS
MOST SEGMENTS

38,778

PANELS IN THE ARECIBO TELESCOPE

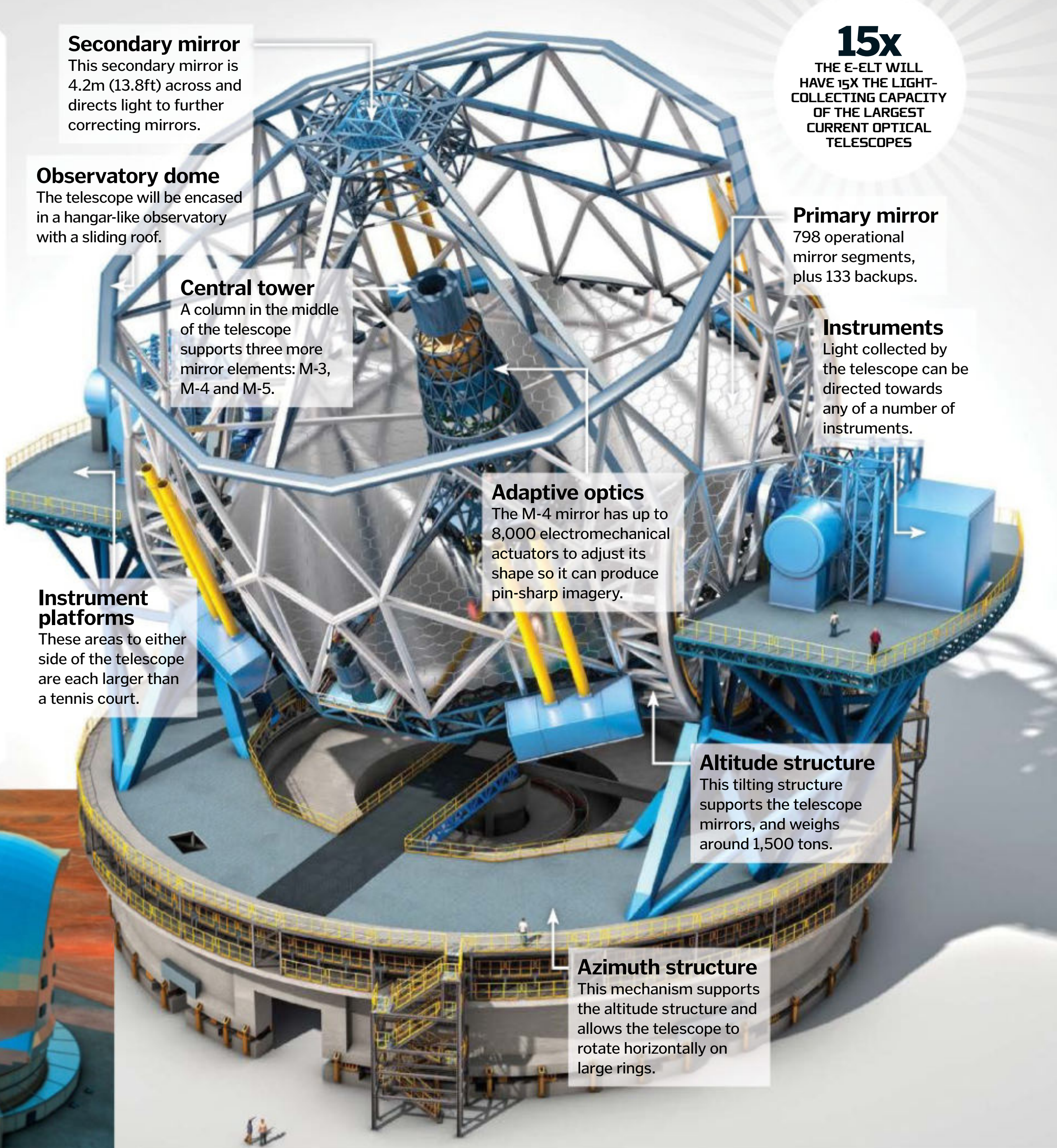
Arecibo's enormous dish is made of nearly 39,000 individual perforated aluminium panels that reflect radio waves to a focus point on a receiver, while letting light through to the forest floor below.

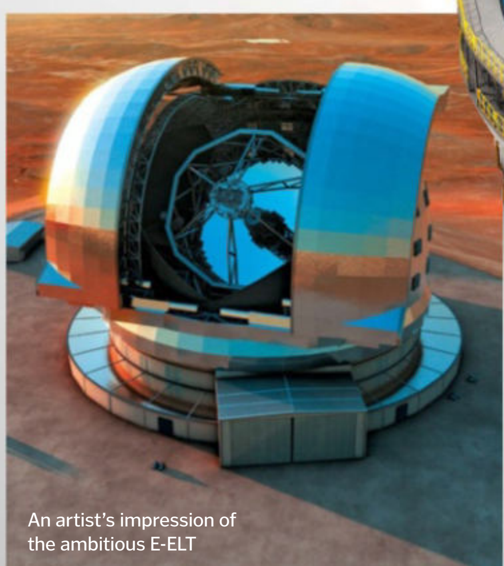
DID YOU KNOW? *Radio telescopes like ALMA can combine signals from telescopes separated by thousands of kilometres*

A new breed of giant

Today's largest optical telescopes are in the ten-metre (33-foot) class, but plans are well underway for the next generation of even more ambitious instruments. For instance, construction should shortly begin on the European Extremely Large Telescope (E-ELT) – a reflecting telescope with a primary mirror surface 39 metres (128 feet) across.

The E-ELT will be built on the summit of Cerro Armazones, a peak in the central area of Chile's Atacama Desert. The telescope's design will involve five separate optical elements, permitting the use of 'adaptive optics' – electromechanical systems that make minute adjustments to the shape of the telescope to correct distortions to the path of light arriving through Earth's turbulent atmosphere. The main mirror itself will consist of 798 hexagonal segments, each 1.4 metres (4.6 feet) across, producing a combined collecting area of 978 square metres (10,527 square feet). Scientists hope the telescope will be operational by the middle of the next decade.




An artist's impression of the ambitious E-ELT

Great discovery: E-ELT

The E-ELT will not be operational for another decade or more, but astronomers at ESO hope it will usher in a new era in astronomy. Sensitive instruments should make the discovery of Earth-like planets around other stars frequent, while the telescope's light grasp will capture the faint radiation from objects closer to the Big Bang than ever before.

Southern behemoth

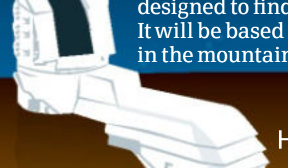
The Southern African Large Telescope (SALT), sited in South Africa's remote Northern Cape province, is one of the largest optical telescopes operating today, and the largest in the southern hemisphere. It has an 11m (36ft) primary mirror made up of 91 hexagonal cells and saw first light in 2005.

Hawaiian monster

Within the next decade, another giant telescope may join the lineup of international observatories on top of Mauna Kea, Hawaii. Funded by an international consortium, the Thirty Meter Telescope (TMT) would be second only to the E-ELT in size and would contain an array of 492 hexagonal mirrors.

New kid on the block

Expected to enter commission in 2020, the Large Synoptic Survey Telescope will study more of space than all telescopes have done before it. It will utilise a 3.2-gigapixel camera and is designed to find new distant galaxies. It will be based 2,682m (8,800ft) high in the mountains of Chile.



"Overhead cranes inside can hold up to 325 tons and move massive objects with extreme precision"

Inside a rocket building factory

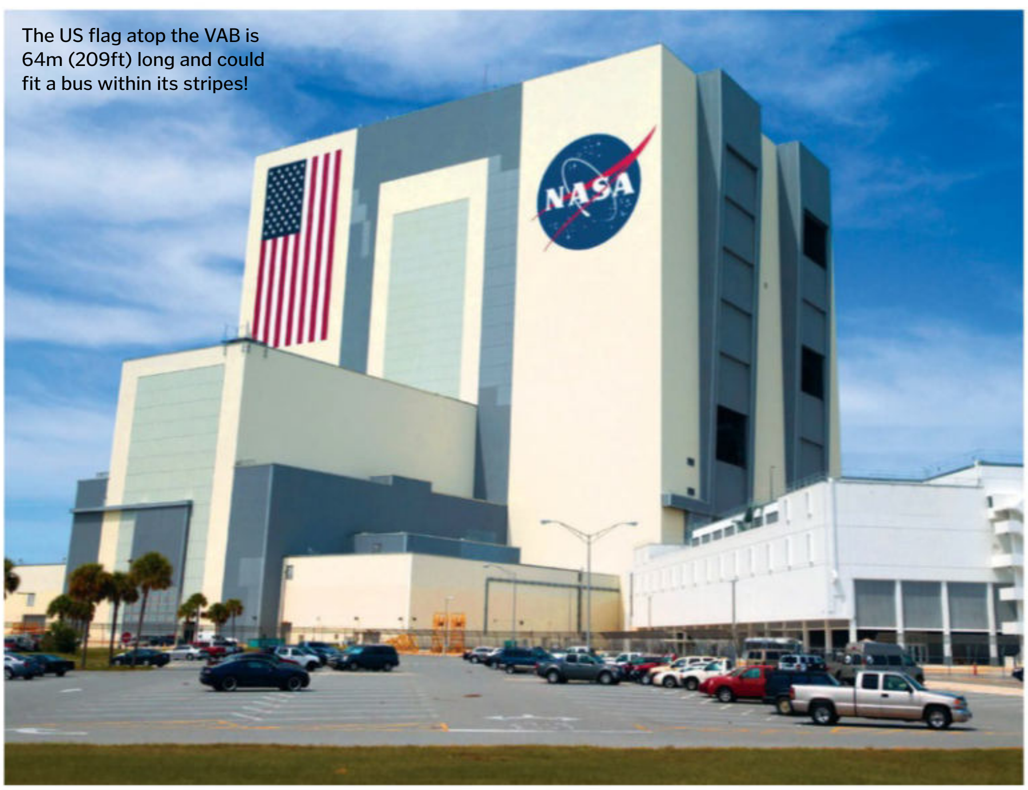
Take a tour around NASA's Vehicle Assembly Building and find out what role it played in the Space Race

Located at the Kennedy Space Center in Florida, the cavernous Vehicle Assembly Building (VAB) helped to build spacecraft used in 135 missions from 1968 until 2011, and is set to do so once again.

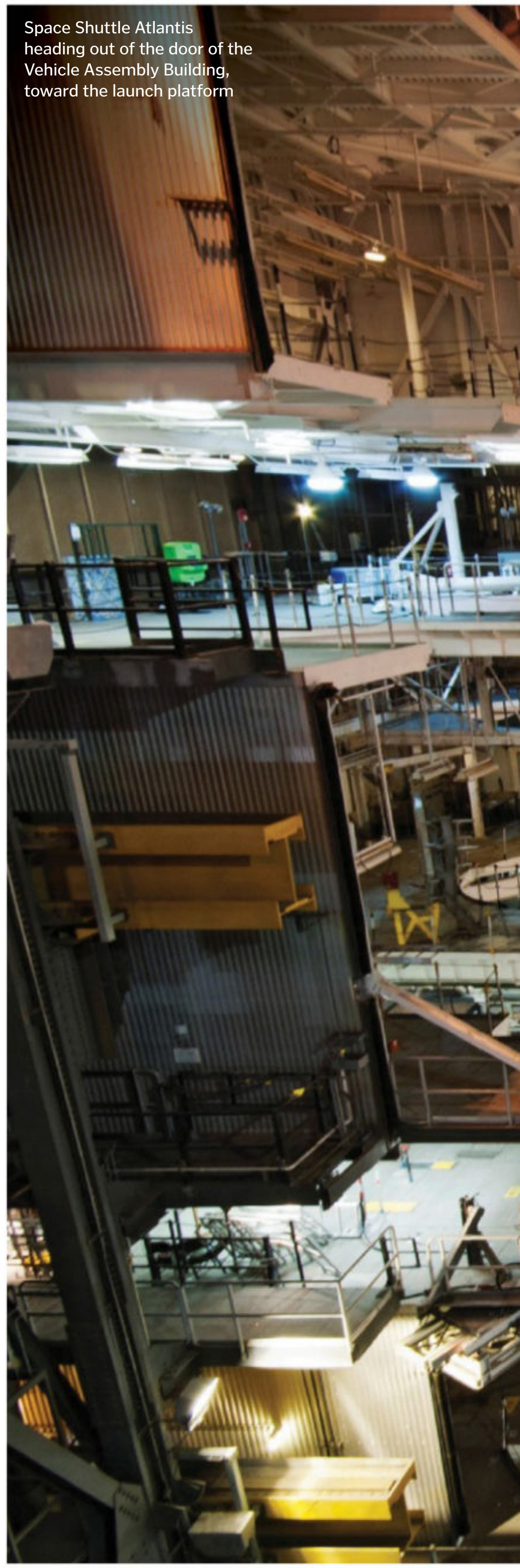
The lower structure of the building was long used for storing rocket components. A transfer aisle connects the sections and leads to a platform which takes vehicles to the launch pad. Overhead cranes inside can hold up to 325 tons and move massive objects with extreme precision. The first rocket assembled in the VAB was the Saturn V, which is still the largest of its kind ever made. Crawler transporters, which are some of the biggest machines ever to move on land, had to be specially engineered to carry the rockets to the launch pad.

Vehicle construction ceased in the VAB after the Space Shuttle was retired in 2011. It was opened to the public for tours around the spaceport to see all the NASA facilities. However, renewed production for future missions has closed the building to the public in February 2014 and it re-opened to begin constructing space vehicles again.

Originally designed to assemble the Apollo and Saturn vehicles, the VAB will now be used to support 21st-century operations. As a result, work is underway to remove old Shuttle-era platforms and introduce ones suited to the new Space Launch System (SLS). The renovation will see a removal of 240 kilometres (150 miles) of Apollo-period cabling in order to update obsolete systems. The first SLS is due for launch in 2017 and will be even larger than the legendary Saturn V. It will be an unmanned Orion crew capsule, which will undertake missions to the Moon and even Mars.



The US flag atop the VAB is 64m (209ft) long and could fit a bus within its stripes!



Space Shuttle Atlantis heading out of the door of the Vehicle Assembly Building, toward the launch platform

RECORD BREAKERS
WHAT'S THE STOREY?

160m

BIGGEST SINGLE-STOREY STRUCTURE

At 160m (525ft) tall, the VAB is the largest single-storey structure on Earth. Also the fourth-largest building by volume at 3.7mn m^3 (129.4mn ft^3). As well as all that it can also boast the world's largest doors at 139m (456ft) high.

DID YOU KNOW? *The first launch from the Kennedy Space Center was a modified German V2 rocket in 1950*

5 more NASA facilities

1 Goddard Space Flight Center

NASA's first spaceflight complex was named after Robert H Goddard who built the first liquid-fuelled rocket. The area covers 5km² (2mi²) and comprises 84 buildings.

2 Jet Propulsion Laboratory

Explorer 1 was built here in 1958. More recently, unmanned craft like Voyager, Galileo and Viking were made here. JPL controls all robotic planetary spacecraft.

3 Armstrong Flight Research Center

Previously known as the Dryden Research Center until this year, this is NASA's HQ for atmospheric flight research and operations. It is used for experimental flight tests and contains many of NASA's top research facilities.

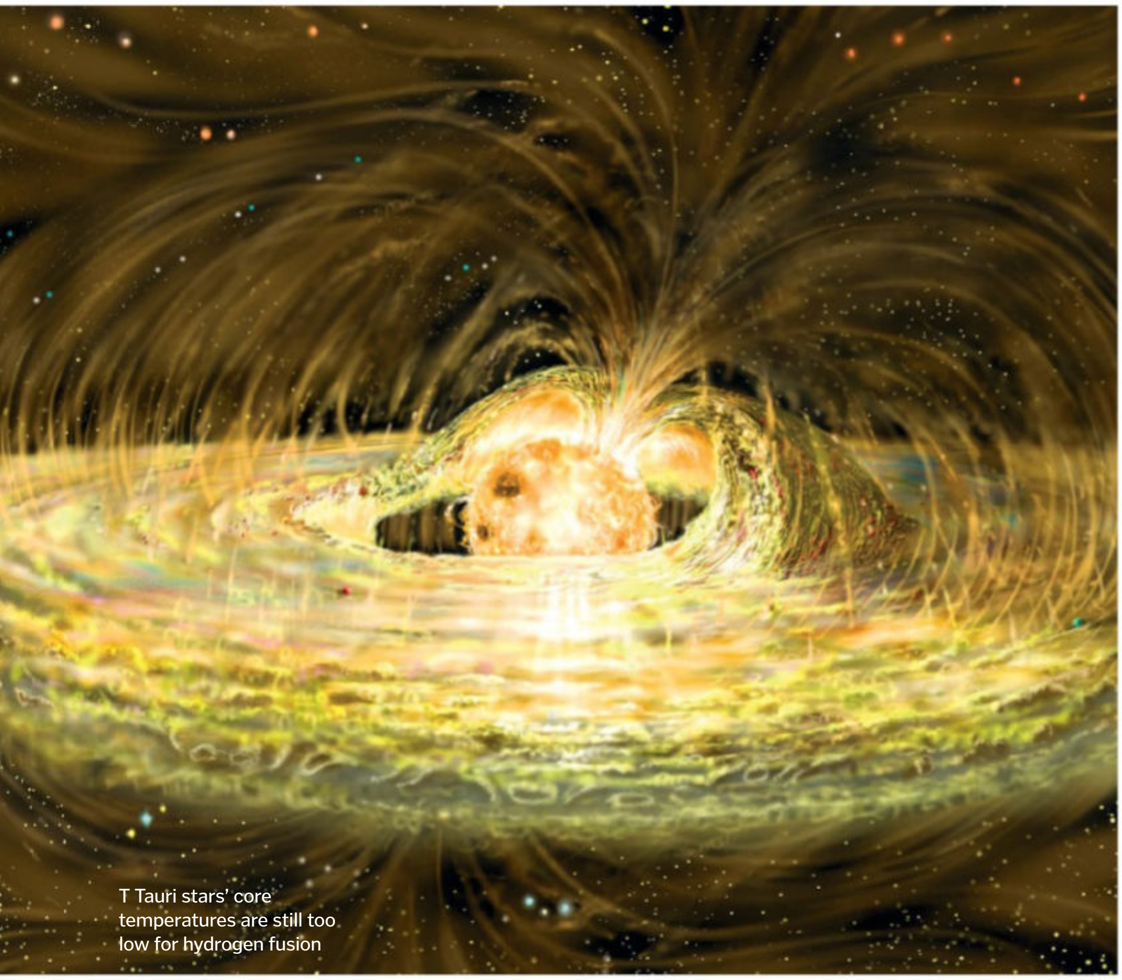
4 John H Glenn Research Center

Containing the zero gravity research facility, the centre has facilities for cryogenics, energy storage and advanced materials and played a critical role in the Apollo missions.

5 Lyndon B Johnson Space Center

The home base for astronauts, previously known as the Manned Spacecraft Center. At 6.6km² (2.5mi²), it has over 140 buildings and specialises in manned missions.

“One of the fascinating things about T Tauri stars is the stellar winds and jets that form around them”



T Tauri stars' core temperatures are still too low for hydrogen fusion

Infant stars

Get to know the youngsters of the night sky

A 'T Tauri' is a type of star that is still very much in its infancy. Usually less than 10 million years old, these stars are undergoing constant gravitational contraction. Over a few million years, this contraction will create enough heat and pressure at the core to ignite hydrogen fusion and turn the T Tauri into a main-sequence star.

One of the most fascinating things about T Tauri stars is the stellar winds and jets that develop around them. These are thought to occur when material floats into the accretionary disc that forms around the star and reacts with it, sending off shoots of gas.

As well as being visually interesting, T Tauri stars – named after the first one discovered – provide a snapshot into our own history. Our own Sun and Solar System went through this process around 5 billion years ago, so studying T Tauri stars should provide us with some great insight into our own origins.

The second red planet

Why Mars isn't alone in the Solar System…

Back in 2003, a planetoid beyond the Kuiper Belt was discovered. Red in colour, it was named Sedna, after the Inuit goddess of the ocean.

Astronomers at Caltech spotted the 1,800-kilometre (1,120-mile) wide body, which is slightly smaller than Pluto, using the Samuel Oschin Telescope. Its size means that Sedna's exact classification is still under debate. Sedna has an elliptical orbit that can take it as far as 140 billion kilometres (87 billion miles) away from the Sun, with an average distance of 5.9 billion kilometres (3.7 billion miles), taking 11,400 years to perform a single orbit.

Sedna's redness is thought to be caused by either tholin, organic aerosols made by fusing methane and nitrogen, or hydrocarbons. Surface temperatures can get as low as -240 degrees Celsius (-400 degrees Fahrenheit).

Sedna is one of the most distant known objects in the Solar System

THE STATS MAVEN FIGURES

2,550kg LAUNCH MASS	POWER 1,135W	LAUNCH DATE 18/11/2013	10months FLIGHT TIME	20 NUMBER OF THRUSTERS	11.4m LENGTH

DID YOU KNOW? *MAVEN won't be the only visitor to Mars in 2014, with India's MOM orbiter due to arrive around the same time*

Next-gen Mars orbiter

Get to know MAVEN and what secrets it's hoping to reveal about the Red Planet

Other than the Moon, there have been more missions to Mars than anywhere else in our Solar System. Some may ask why we are still sending probes there rather than to other, less charted worlds.

A big reason is obviously logistics. Although Venus is technically our closest neighbour (on average), Mars's more hospitable conditions and hints of a watery past make it a far more attractive prospect. Although there have been over 40 planned missions to Mars since 1960, many have failed – some not even getting past Earth's orbit. Of those deemed successful, only a handful remain operational today and most of those are fast approaching retirement.

Hence why the new kid on the block, MAVEN – or to give it its full name, Mars Atmosphere and Volatile Evolution – is currently en route there. Scheduled to arrive in September 2014, this probe's remit is to focus on the Red Planet's upper atmosphere and how it interacts with the solar wind. The ultimate goal is to determine how the loss of atmospheric gases over millennia has shaped, and continues to shape, the Martian climate.

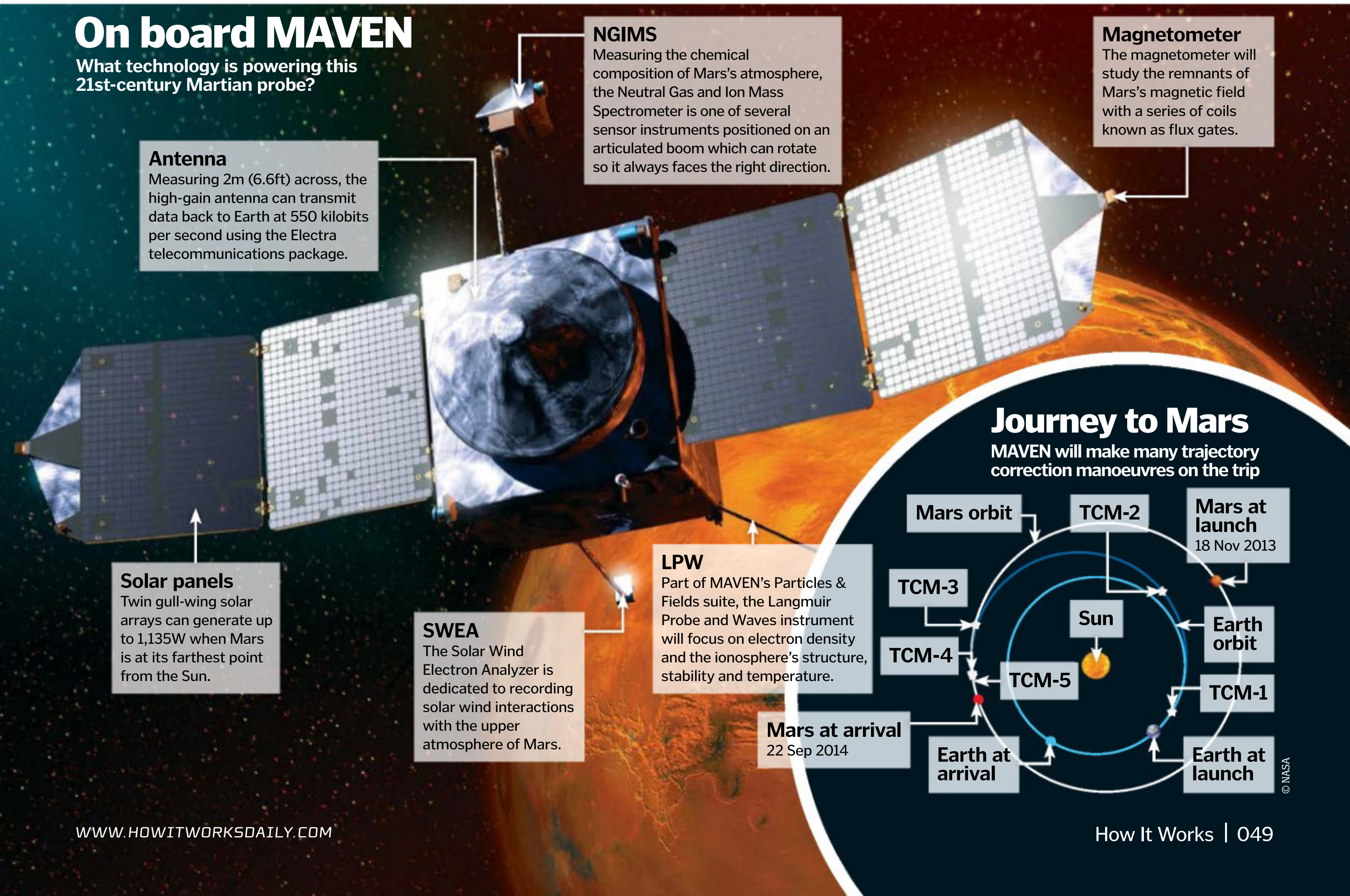
To conduct its studies, the orbiter is kitted out with a host of hi-tech equipment packaged into three instrument suites, including tools for analysing subatomic particles, spectrometers and magnetometers to name just a few (more detail in the annotated image).

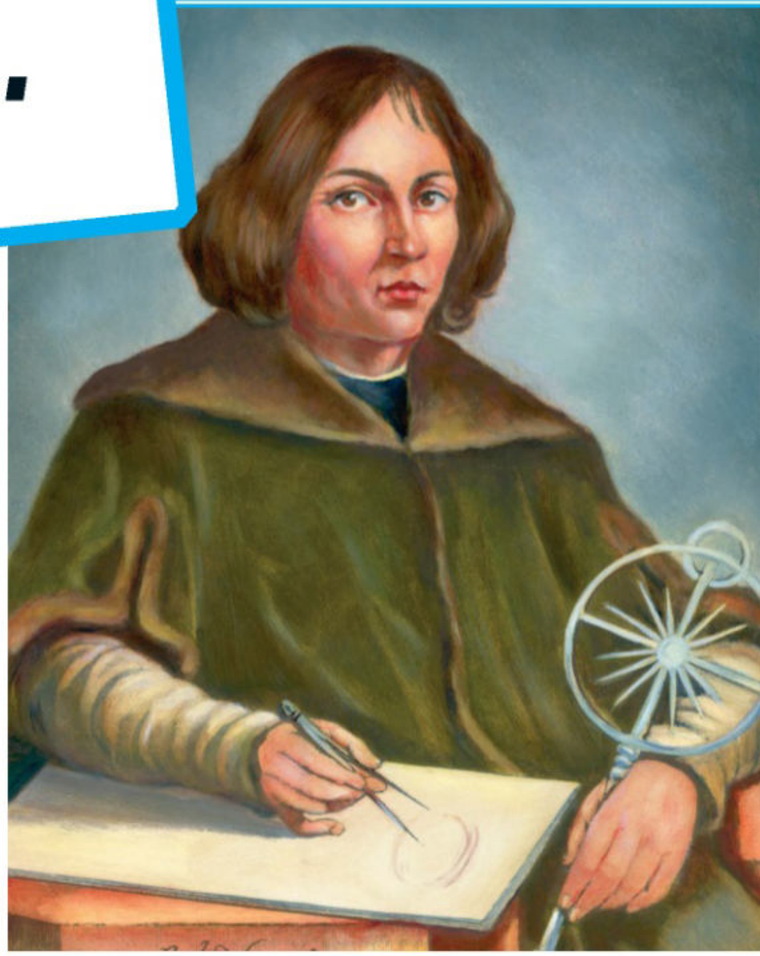
1,700 litres (450 gallons) of hydrazine propellant is the spacecraft's main power source, though the majority of this will be burned up during the journey and the final manoeuvres into Martian orbit. Once in position Mars's gravity will do most of the work, and two solar array wings provide power for the state-of-the-art instruments. Due to the eccentric nature of its orbital path, distance from the surface will vary by more than 6,000 kilometres (3,730 miles), coming to within 150 kilometres (93 miles) at its closest point.

As well as its scientific duties, MAVEN will also act as a vital communications relay between rovers on the surface, such as Curiosity, and space scientists here on Earth. This latter role has taken on more urgency after a series of unexplained glitches recently on the Mars Reconnaissance Orbiter – one of the existing data transfer satellites.

On board MAVEN

What technology is powering this 21st-century Martian probe?





Nicolaus Copernicus

How the observations of a 16th-century Polish Catholic monk set the Scientific Revolution into motion and realigned Earth's place in the universe…

Until Copernicus, the most widely accepted theory of the universe was that the Earth was at the centre, and the Sun, Moon and planets all revolved around it. This was an idea that had been advocated by Aristotle millennia before, then by Ptolemy and was fiercely backed by religious leaders. Any who dared to challenge this dogma were accused of heresy – a crime punishable by death.

However, the Ottoman conquest of Constantinople, a bastion of Greek culture, forced the city's scholars to flee west. With them they brought ancient knowledge and classical methods of observation and questioning as a way to solve the great mysteries of the universe. At the same time, growing scepticism of the Catholic Church and England's break from Rome meant that reason was beginning to take the place of religion in academia, a realm that had before been largely governed by Christian belief. As a result, Renaissance astronomers began to challenge Aristotelean physics.

One of these stargazers was Mikołaj Kopernik, or as he has come to be known, Nicolaus Copernicus. He was born in 1473 in Torun, Poland. When he was just ten years old, his father died and his uncle, a bishop, took the boy under his wing. He supported Copernicus through his studies at the University of Krakow, which he began in 1491, in the heyday of the Krakow astronomical-mathematical school, where he laid down a strong foundation for his later mathematical achievements.

In 1496, he moved to Bologna, Italy, to study canon law, and rented a room in the house of prominent professor and astronomer Domenico Maria de Novara. He became his disciple and assistant and for the first time was met with a mind that dared to challenge the existing theories of the cosmos.

On completing his studies, Copernicus returned to Poland to live with his uncle, acting as his secretary and physician at the same time. During this time he began work on his now famed heliocentric theory. In 1512, his uncle died and Copernicus moved to Frombork, where he took up a position as a canon – an administrative appointment in the Church.

Here he had more time to devote to his astronomical studies, and built himself a small observatory from which he could plot the movement of the stars. Around 1514, he outlined his theories in a short, anonymous manuscript referred to only as *Commentariolus*, in which he summarised his heliocentric model of the Solar System, where the planets orbited the Sun. Although he only distributed the manuscript among a few of his friends, a buzz began to build around Copernicus and his unconventional theories, but they also sparked controversy in the Catholic Church.

While the threat of persecution did not deter Copernicus from developing his theories, he was reluctant to publish them and kept his findings secret for decades. However, in 1540 his pupil Georg Joachim Rheticus convinced him to publish his book *De Revolutionibus Orbium Coelestium* (*On The Revolutions Of The Heavenly Spheres*). In 1543, as Copernicus lay on his deathbed, the first-ever printed copy was placed into his hands. The Scientific Revolution had begun in earnest.

A life's work

We pick out some of the milestones over this astronomer's lifetime

1473
Copernicus is born to his namesake father Nicolaus, an affluent copper merchant, and mother Barbara in Torun.

1491
Copernicus studies painting and mathematics at the University of Krakow at 18 years of age.

1496
After graduating he moves to Italy to study canon law, but is drawn towards astronomy.

1503
Copernicus returns to Poland to live with his uncle, acting as his secretary and physician.

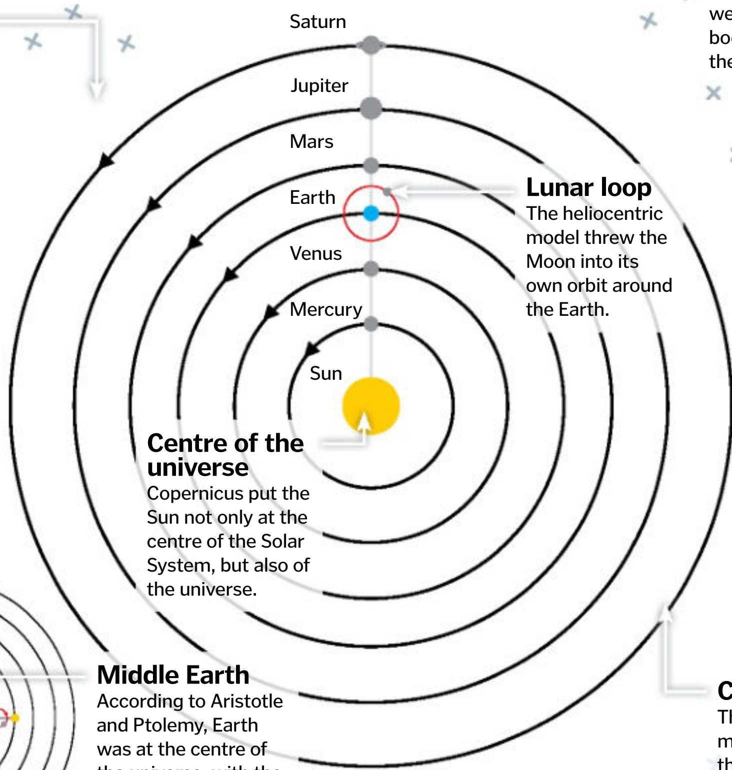
1512
After his uncle's death, Copernicus moves to Frombork (pictured right) in northern Poland to work as a church canon.

A cosmic reshuffle

Copernicus's theories knocked the Earth from the central position it had held for millennia, but why was the Copernican model so radical?

Missing planets
Uranus was not accepted as a planet in our Solar System until 1783 and Neptune wasn't spotted till 1846.

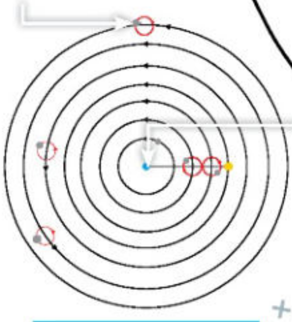
Fixed stars
Copernicus failed to discover that the stars were not immovable, but bodies in motion within their own solar systems.



Lunar loop
The heliocentric model threw the Moon into its own orbit around the Earth.

Epicycles
The geocentric model suggested planets had their own miniature 'epicycles', but Copernicus did away with this idea.

Centre of the universe
Copernicus put the Sun not only at the centre of the Solar System, but also of the universe.



Middle Earth
According to Aristotle and Ptolemy, Earth was at the centre of the universe, with the Sun and other planets orbiting around it.

Circular motion
The new model maintained the theory that the planets' orbits were circular, not elliptical as was later determined.

Geocentric model

Heliocentric model

Top 5 facts: Nicolaus Copernicus

1 Multitalented man
Copernicus's skills were not limited to astronomy. He was also a physician, scholar, economist, translator, mathematician, artist and diplomat, among other things.

2 It's in the chemistry
The chemical element Copernicium is named after Copernicus. Its discoverers wanted to name the element after a scientist who did not receive enough recognition in their own lifetime.

3 Bad money drives out good money
In 1526, Copernicus developed a monetary theory, now called Gresham's Law, which was used to stabilise the currency in Poland and is still a principal concept in economics today.

4 The centre of everything?
Contrary to popular belief, Copernicus didn't actually believe that the planets of the Solar System orbited the Sun itself, but around a centre that was near to it.

5 Doctor Copernicus
Though he had a brief stint studying medicine, he never gained a medical degree, yet acted as his physician to his uncle and then his uncle's successor for many years.

In their footsteps...

Galileo Galilei
Galileo was an Italian polymath known for his improvements to the telescope, numerous astronomical observations and his fierce support of Copernicus's heliocentric model. In contrast to Copernicus, Galileo was not afraid to speak up about his views. He was put on trial for heresy, but narrowly avoided death by agreeing to abandon his Copernican beliefs.

Edwin Hubble
Hubble was the first to discover the existence of other galaxies outside of the Milky Way and to theorise that the universe is expanding. While these findings helped shake off the idea that the Earth is at the centre of the universe, Copernicus's research contributed to Hubble's work, and he even named his cat after him. Of course, NASA's famous space telescope is named after Hubble.

The big idea

The geocentric model of the universe that placed the Earth at the centre was plagued with inconsistencies. Instead, Copernicus's heliocentric model set the Sun at the centre of the universe, with the planetary bodies revolving around it and the Moon orbiting the Earth. Copernicus also proposed that the distance between the Earth and Sun is only a fraction of other stars' distance from the Earth and Sun, and that the stars were fixed. Though some of his theories have since been proven wrong as well, his model was to provide an invaluable basis for modern astronomy.

1514
Copernicus produces a short manuscript known as the *Commentariolus*, where he outlines his heliocentric theories.

1532
Copernicus completes *De Revolutionibus Orbium Coelestium*, but is reluctant to publish it for fear of religious persecution.

1539
The astronomer takes on his first and only pupil, Rheticus (right), who persuades him to publish his work.

1543
The first copy of his book is published, but Copernicus dies shortly after from a stroke, aged 70.

Science of forensics

What goes on behind the police tape in the real-life CSI?

The area of forensic investigation has captured the public's imagination ever since global smash TV show *CSI: Crime Scene Investigation* first exploded onto our screens in 2000, but incredibly it's a field of criminal investigation that can trace its origins all the way back to the seventh century.

History has it that a market stall owner used the fingerprints of a man who owed him money to prove his identity and, from these inauspicious beginnings, a whole new area of criminology was created.

Today, the first people (after police) at the scene of a crime will be the CSI team, keen to preserve the integrity of the environment to boost the chances of capturing the perpetrator without any evidence being disturbed, although the word 'team' can be something of a misnomer.

Depending on the size of the local force, the CSI team can often consist of a single field officer, trained in multiple areas, who will work methodically around the room, first taking photos, and then collecting clues such as fingerprints, clothing, hair and broken glass which could lead to the culprit. However, for large-scale incidents like murders, up to four people will be involved, including a specialist photographer and a crime scene manager.

Alexandra Otto was a crime scene investigator for 11 years before moving to Bournemouth University, Dorset, UK, to become a demonstrator of forensic science in 2006. In an interview with How It Works she explains the process stage by ▶

At the crime scene…

How does a forensics team approach the scene of a murder?

Prints & marks
All surfaces, door handles and glasses etc will get dusted for prints and suspicious marks on windows, floors or walls swabbed for DNA traces.

Security
The area will be cordoned off with tape and other security measures put in place to ensure nobody tampers with the crime scene or any evidence.

Murder weapon
Officers will scour the room for any obvious weapons or clues which could reveal the murder weapon, eg bullet holes.

Kitted out
Investigators will wear clean protective clothing and gloves to avoid contaminating the scene and tainting potentially incriminating DNA.

Forensic toolkit

The must-have gear no CSI should be caught without

Mask and gloves
These essential pieces of protective wear ensure that no investigators contaminate a crime scene with their own DNA.

Evidence bags
All pieces of evidence will be carefully placed in these sterilised plastic bags for later analysis in a laboratory.

Digital camera
A CSI will take hundreds of photographs of the scene as well as the surrounding area to serve as evidence in court.

5 TOP FACTS FORENSICS MYTHS

Blue light finds blood
1 While an alternative light source (ALS) can find bodily fluids, blood is located using luminol, a chemical that reacts with haemoglobin and causes the blood traces to glow.

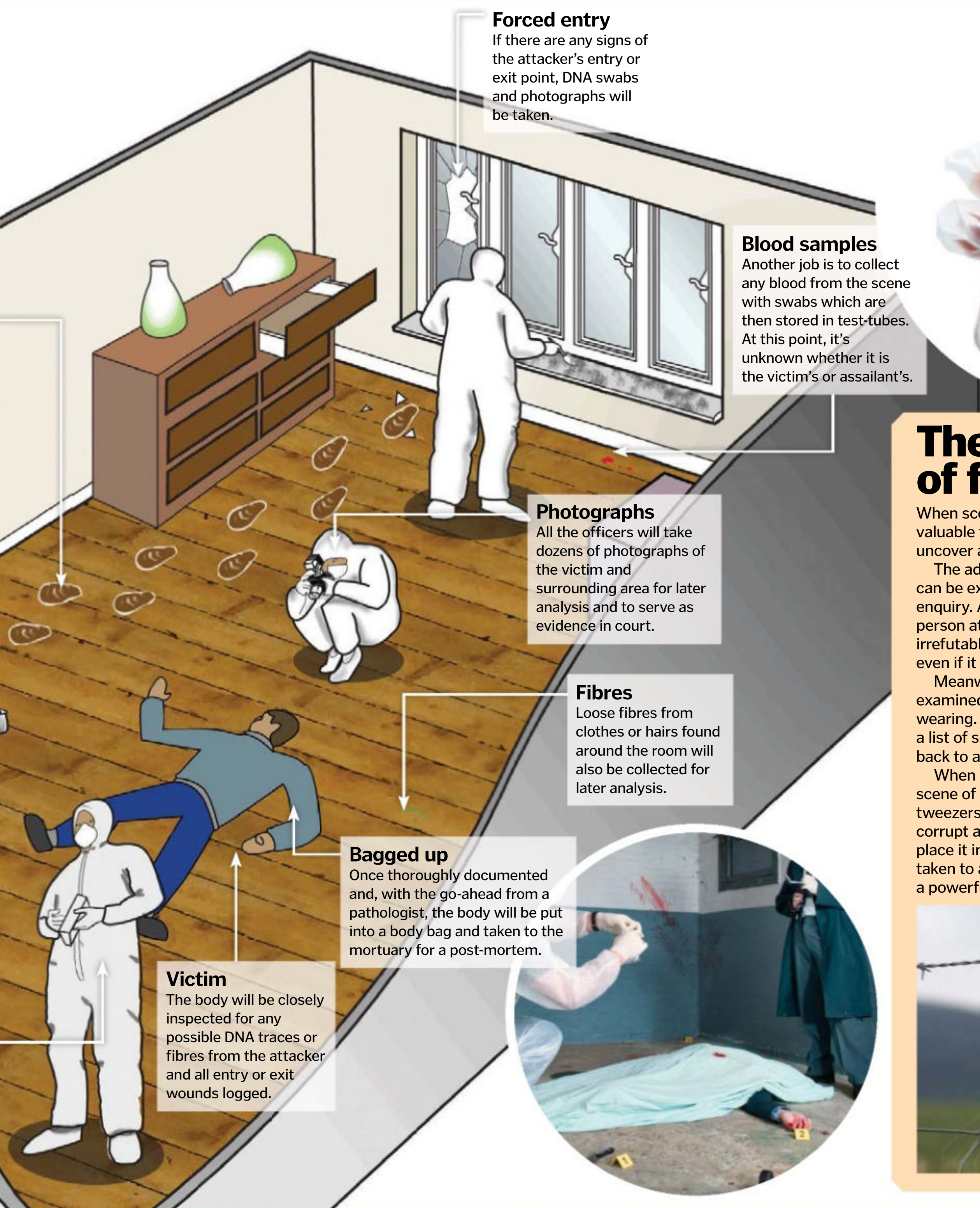
Superfast results
2 In stark contrast to the seconds or minutes that DNA analysis takes on television, a real DNA test will usually take around 7-14 days to return any meaningful data.

Bullet = gun
3 While you can often match a bullet to the gun that fired it, if the bullet has been damaged or the gun has been modified, making a match is much more difficult.

DNA always gets results
4 Even if investigators find DNA, they can't always establish whose it is. Not many people have their DNA on file, so only people with previous convictions get flagged up.

Chalk outline
5 Chalk outlines are not used to mark around dead bodies as doing so may contaminate evidence. Instead, photos and tape markers are used for analysis of the scene.

DID YOU KNOW? *CSI has been named the most watched show in the world five times in the last seven years*



Forced entry
If there are any signs of the attacker's entry or exit point, DNA swabs and photographs will be taken.

Blood samples
Another job is to collect any blood from the scene with swabs which are then stored in test-tubes. At this point, it's unknown whether it is the victim's or assailant's.

Photographs
All the officers will take dozens of photographs of the victim and surrounding area for later analysis and to serve as evidence in court.

Fibres
Loose fibres from clothes or hairs found around the room will also be collected for later analysis.

Bagged up
Once thoroughly documented and, with the go-ahead from a pathologist, the body will be put into a body bag and taken to the mortuary for a post-mortem.

Victim
The body will be closely inspected for any possible DNA traces or fibres from the attacker and all entry or exit wounds logged.

The importance of fibres

When scouring a crime scene, two of the most valuable finds that a forensic officer can uncover are hair and clothing fibres.

The advantage of finding a hair is that DNA can be extracted from it, opening a line of enquiry. Although it can't directly place a person at the scene like fingerprints, it is irrefutable proof that there is a link somewhere, even if it has been planted.

Meanwhile, fibres of clothes can be minutely examined to determine what someone was wearing. This can then be used to whittle down a list of suspects as certain fibres can be traced back to a specific manufacturer.

When anything of this nature is found at the scene of a crime, forensic officers will use tweezers to pick up the item, so as not to corrupt any potential DNA, and immediately place it in an evidence bag. The bag is then taken to a lab, where it can be examined under a powerful microscope and any DNA extracted.

Fingerprinting powder
Two different types of powder are used at the crime scene; which one depends on the type of surface.

Tape
Adhesive tape is used to lift a copy of a fingerprint from a surface.

Luminol
This is a chemical which glows in the dark in the presence of blood, illuminating even trace amounts.

Flashlight
A torch is essential for looking in dark nooks and crannies for crucial evidence or during crime scenes at night.

Tweezers
In order to avoid smudging potential fingerprints or damaging fibres, tweezers are used to pick up small pieces of evidence.

> "Before even entering the room, we will scour the area outside the crime scene to see if there are any clues"

stage from the moment they get the call to the scene to the end of the case.

"First, we'll get a call from the control room that took the report of the incident, head down to the crime scene and talk to any police officers or home owners. Before even entering the room, we will scour the area outside the crime scene to see if there are any clues we can find.

"Then, we will move inside the room, having put on protective suits, gloves and masks. The masks are to avoid any chance of us accidentally contaminating the scene with saliva or anything like that. We will take lots of photos of all areas of the room. These will primarily be for the prosecution, but they are also disclosed to the defence. Next, we go around collecting evidence in bags, such as any blood on a window, fibres from clothes or envelopes the intruder may have opened.

"The next stage is to dust for fingerprints. We will then use tape to lift the prints, which will be bagged in a special envelope and sent to a fingerprints expert, while the rest of the evidence goes to a lab. We would never touch a body until the forensic pathologist has been and studied it. Then the body would get put in a body bag and taken to the mortuary.

"Once all the evidence has been analysed in the lab, we would get the results, which we would pass to the CID who would continue the investigation. We could get called to court to give our side of the investigation, but the detective and analytical work are done by the police and lab teams."

Until fairly recently, much of the laboratory work carried out in Britain was done by the

Anatomy of a fingerprint

What the experts are looking for when trying to match a print

Loops
This pattern will rise up at an angle, curve over and swoop back down, returning back to the starting point of the pattern.

Whorls
These are individual rings, each one encircling the one inside it. Just over a third of fingerprints look like this.

Arches
The least common of all fingerprints, these look a bit like a hill, swooping up from the left, then down toward the right.

Independent ridge
A long ridge which isn't connected to any others.

Enclosure
This is where two ridges split, then rejoin, forming an enclosed loop.

Bridge
A ridge connecting one long ridge with another, bridging the gap between the two.

Bifurcation
Looking like a fork, this is where a ridge naturally splits into two.

Dot
Similar to the independent ridge in that it isn't connected to any other ridges, but it's much shorter.

The process of fingerprinting

1. Collection

Fingerprints can be found in several ways. The most common is taking a high-resolution photograph of a print that is already visible. However, if no prints are visible at a scene, investigators can dust surfaces with powders such as aluminium flakes, take pictures, then collect them by sticking tape onto the powdery surface and removing them along with the imprint. An alternate light source (ALS) can be used in a darkened room.

2. Processing

The print is fed into a computer, which analyses the patterns and tries to find a match with any on its database. If any matches are flagged, fingerprint experts examine the two images by eye.

3. Decision

Examiners use the ACE-V method in fingerprint analysis, which stands for Analysis, Comparison, Evaluation and Verification. The first stage is to establish if there is enough of a print in terms of quality or quantity to verify a match. After that, they look at images of the print and the potential match to see if they are similar. If it's decided that they do match closely enough, the final stage is to bring in a second examiner to perform the same process for verification.

Fathers of fingerprinting

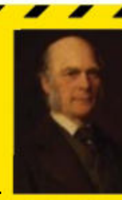
We have a few people to thank for the development of fingerprint forensics

1686
Marcello Malpighi notes fingerprints are unique to the individual, after studying patterns on our fingers.

1858
Magistrate of Indian district Hooghly, William Herschel uses fingerprints to force locals to confess to crimes.

1880
Henry Faulds publishes his reseach in *Nature*, suggesting that fingerprints could be used to catch criminals.

1892
Sir Francis Galton writes the book *Finger Prints* and devises a method to identify and record fingerprints.



STRANGE BUT TRUE
A HUMAN TOUCH

Which Australian animal has human-like fingerprints?

A Kangaroo **B** Koala **C** Wombat

Answer:
Even when viewed under a microscope, it is practically impossible to distinguish a koala's fingerprints from human ones. This is thought to be a recent evolution as fellow marsupials don't have human-like fingerprints.

DID YOU KNOW? *The acid in quicklime is able to erode our fingerprints, although they will grow back in around 30 days*

Forensic Science Service (FSS), which was run by the government, but losses of around £2 million ($3.3 million) per month forced the department to close. The workload for analysing the results of the crime scene then got contracted out to private companies.

"The private companies are very good," reveals Otto. "The only problem is contamination. The great thing about the FSS was that they were world-renowned and their labs were always incredibly clean. Unfortunately the private companies sometimes aren't quite so careful and contaminations do occur. When you're working with DNA, which is obviously such a small thing, you have to be really careful."

After removing a body from a crime scene, it's placed in a sterilised bag and transported to a mortuary where it's kept until the forensic pathologist is able to perform a post-mortem, determining time and cause of death.

Meanwhile, lab analysis of any pieces of evidence is taking place. This can be anything from looking at a piece of thread under a microscope to see what the suspect was wearing to processing any DNA fragments to see if there is a match on the database.

A fingerprint is left on a surface due to the sweat glands in the finger creating a latent mark. Alternatively, if a person presses with enough force in wet paint or other malleable surfaces, this would also leave a print.

"Smooth surfaces like glass will require a flake powder containing aluminium or gold flakes," Otto explains. "Rough surfaces will need a more granular powder. This powder ▶

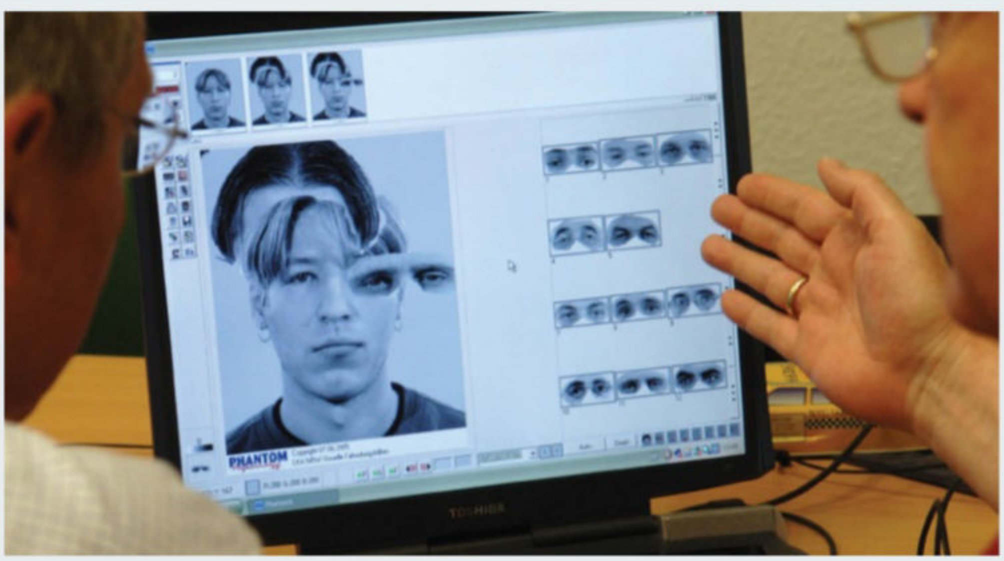
DNA profiling

The discovery of DNA was a massive milestone in the field of forensics. Watson and Crick proposed the idea of the double helix in 1953, but in 1984 British geneticist Alec Jeffreys discovered a method to use variations in a person's DNA to identify them.

The most common method of DNA profiling uses short tandem repeats (STRs). These are structures within the human genome consisting of one to five bases and are repeated thousands of times through the DNA system. When DNA copies itself, mutations occur, giving each individual their unique code. Profilers will take 10-13 STR markers from DNA found at the scene of a crime and compare that with DNA taken from the person they are interested in.

STRs are useful in DNA identification because the STR markers vary noticeably in humans, reducing the chance of an error, and also because they can be easily magnified when profilers are inspecting the DNA strands.

A CSI will spend a lot of their time in the lab, analysing evidence collected at crime scenes



Putting a face to DNA

Until now, the only clues the police were able to use to physically identify a criminal is witness or CCTV evidence. However, teams from Erasmus University Medical Centre in Rotterdam and Pennsylvania State University have identified five genetic variants that have an effect on the face. This means that the same DNA that can identify who you are on the inside could in the future also help police construct a reasonably accurate re-creation of a face, including the tip of the nose, position of the eyes and general face shape.

This breakthrough was achieved by making 3D images of nearly 600 people from a variety of ethnic backgrounds and linking the differences in face shape to the differences in DNA, isolating the genes that controlled what we look like.

While still not yet fully tested and some way from being able to be used as evidence in court, this new method of forensic profiling has very exciting potential to help investigators drastically narrow down their list of suspects.

> "Now that people are aware of the power of forensic evidence, criminals are able to manipulate the system"

adheres to the sweat that creates fingerprints so we can get a clear image of the print."

As fingerprints are unique to the individual, the discovery of fingerprints on a doorframe or a person's body provides irrefutable proof that they were there. While fingerprints found at a scene cannot be dated, and the added confusion of planted evidence the culprit could use to frame someone else, fingerprints provide an invaluable resource to police officers who need to link a suspect with a location.

Once fingerprints have been collected, they are analysed by a dactyloscopy expert and run through a computer that will search its database of fingerprints, collected over several decades, to try and find a match.

The whole basis of fingerprint evidence is centred on the unique pattern of whorls, loops and arches that make up every fingertip. As yet, no one has ever found two people with exactly matching fingerprints, so a positive match is taken as fairly solid evidence of a person's connection with the crime.

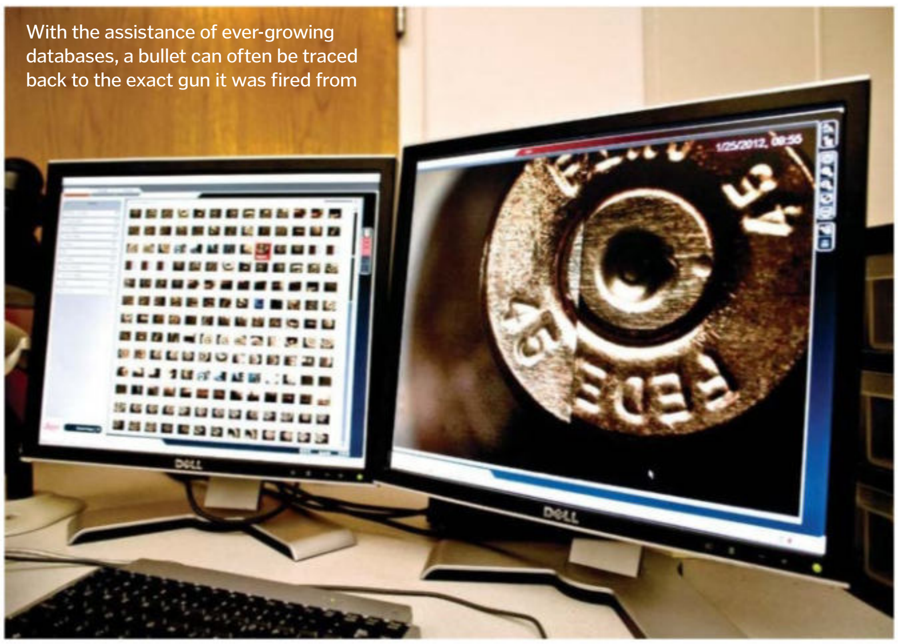
Recent advances in fingerprinting have enabled forensic investigators to even detect high-quality fingerprints from food, a previously tricky area of investigation. A modified form of powder suspension, which is a tar-like substance, will reveal a fingerprint quite clearly even on smooth surfaces, meaning that we now have another way in which to connect people with a crime.

The other key area for forensic investigators is DNA matching. This is a much more recent development, with the technique only emerging in the 1980s, but is able to create matches with incredible accuracy. DNA profiling is where a section of a person's DNA, which is unique to them, is matched with DNA found at a crime scene, which can come in the form of blood, a strand of hair or even oil from a nose print that had been pressed up against a window. If a match is found, you can be fairly certain someone was there, if not when or why.

Obviously though, linking a person with the scene of the crime won't automatically result in a conviction. Now that people are aware of the power of forensic evidence, criminals are able to manipulate the system, planting DNA evidence to throw investigators off the scent. Forensic evidence can go as far as showing who has touched a certain object or whose DNA was found in the area, but it is still up to the police to decide what to do with the evidence put in front of them, much like non-forensic evidence such as witnesses and alibis.

Unfortunately, the other key limitation to DNA and fingerprint evidence is that the person to whom they belong needs to be known to the police. Fingerprints and DNA are run through


Another aspect of crime scene investigation is collecting and examining ballistics evidence, if a gun has been used in the crime


With the assistance of ever-growing databases, a bullet can often be traced back to the exact gun it was fired from

Ballistics in focus

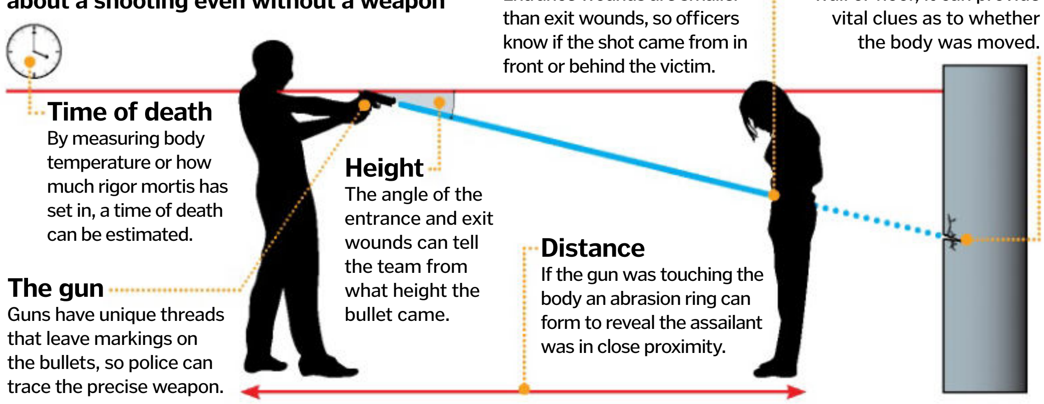
Unless a gun has been modified or the ammunition badly damaged, forensic officers are often able to trace a bullet back to the weapon that fired it, due to marks made by the firearm's unique pattern of grooves and threads.

When establishing the cause of death, ballistics experts and medical officers will work together to determine various aspects of the shooting, such as the distance and angle from which a person has been shot judging by the entry wound and potential exit wound.

Assistance to law enforcement officers now comes in the form of the instant shooter identification kit, which can work out in minutes if a person has recently fired a gun by analysing gunpowder residue on their hands.

Tracking a bullet

The ballistics team can tell many things about a shooting even without a weapon



KEY DATES
HISTORY OF FORENSICS

1788
JC Mayers writes that 'the arrangement of skin ridges is never duplicated in two persons'.

1886
Henry Faulds believes fingerprints could be used to identify criminals. He is rebuffed by Scotland Yard.

1953
Watson and Crick discover that DNA is handed down by a person's parents and is unique to the individual.

1984
Alec Jeffreys develops genetic profiling, which links DNA from a crime scene with DNA taken from a suspect.

1988
Colin Pitchfork becomes the first person to be convicted in the UK using DNA evidence.

DID YOU KNOW? *Studying insects at a crime scene is called forensic entomology. Development of fly larvae can reveal time of death*

the national database to find a match, but if the police do not have either on file, they will hit a dead-end in the investigation. An officer can only take DNA and fingerprints when someone is arrested and a recent law in the UK has determined that anyone who hasn't been convicted of a qualifying offence has to have their records destroyed within six months. However, the benefit of the DNA database is that more and more cold cases are being solved, due to people's DNA being taken, fed into the computer and matched with DNA taken from a crime scene years ago, leading to many retrospective convictions.

Forensics alone cannot force a conviction, but they certainly can assist the police in constructing a case for the prosecution.

Whenever a gun is involved in a crime, ballistics is another major area that falls under the forensics team's remit.

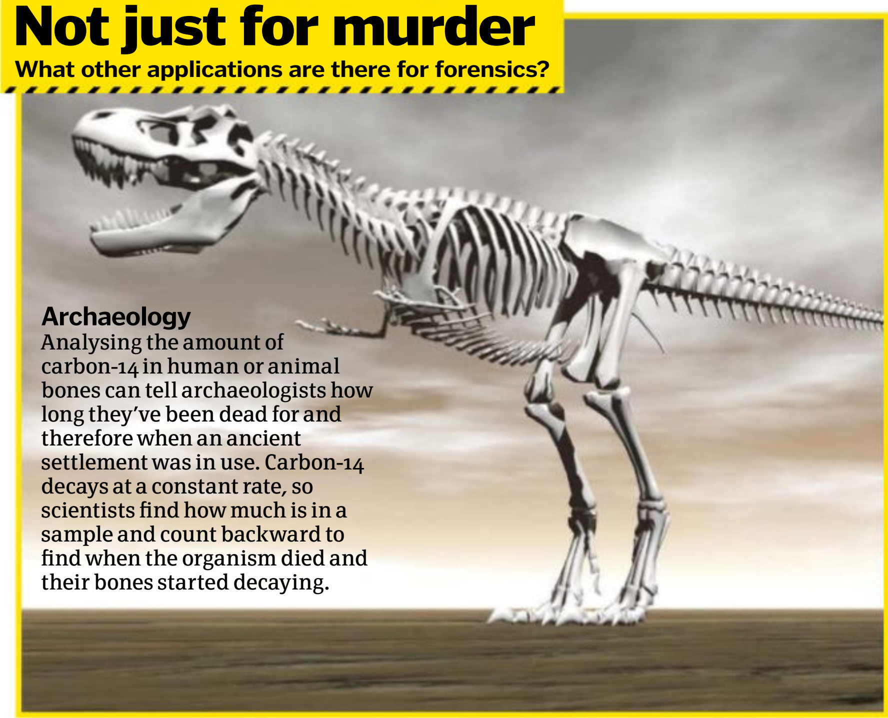
"One of the things we can determine is the directionality of ballistics, so where the bullet came from", Otto explains. "Apart from if a gun is modified, matching the bullet to the gun is a very precise science. Each gun has grooves that are particular to that exact firearm, not just the brand, so we can trace the gun with real certainty. Less reliable is firearm residue. Studies here have shown that there is a real similarity between gunpowder residue and brake dust, for example, so that is an area that needs further investigation."

We have to ask Otto about the influence of *CSI*. The hit US TV show has been phenomenally successful in the 14 years since its premiere and has spawned two direct spin-off series, *CSI: Miami* and *CSI: New York*, as well as inspiring several other detective shows, but is its immense success a boost or hindrance to the world of forensic investigation?

"Of course I watch *CSI*. I need to know what my students are watching. The show is very good, but it does give people a different idea about crime scene investigators. In the show they do everything. They interrogate witnesses, forensically investigate the scene, do the lab work, everything. In reality, we don't do much of that side of things at all. In fact, when my students first arrive I tell them that the life of a CSI is not like on the TV at all.

"It does give the wrong impression about how things work too. Whereas they get DNA results straight away, we generally have to wait about a week to two weeks minimum for results to come back. Having said that, forensics is quick in the courts. It helps to identify the person because of the individuality of DNA, and it has been proven that DNA profiling stands up in the court of law. I don't think the advantages of DNA can ever be overvalued."

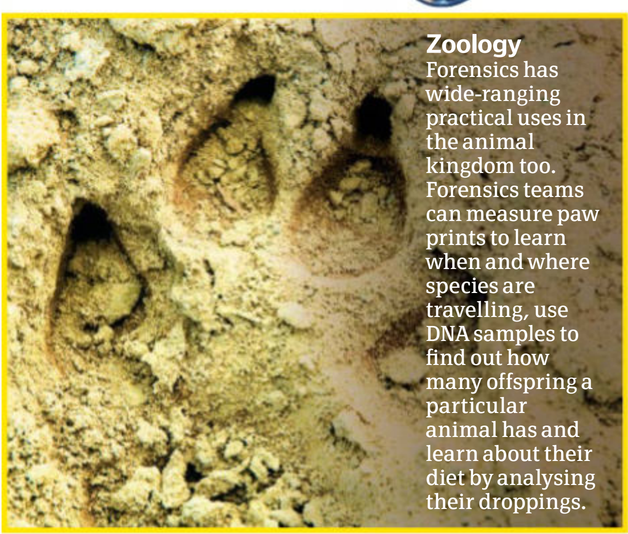
Not just for murder
What other applications are there for forensics?



Archaeology
Analysing the amount of carbon-14 in human or animal bones can tell archaeologists how long they've been dead for and therefore when an ancient settlement was in use. Carbon-14 decays at a constant rate, so scientists find how much is in a sample and count backward to find when the organism died and their bones started decaying.

Reuniting families
Families that have been separated through adoption, abduction or any number of reasons like natural disasters can be reunited through their DNA. By analysing the DNA of child and parent, geneticists can establish a definitive match and provide cast-iron proof of the relationship.

Fraud
Technology is a key part of many criminal investigations, so the field of technology forensics is growing. Experts can determine the last person to use a computer, locate and date emails and even pinpoint a person's current location using IP addresses.



Zoology
Forensics has wide-ranging practical uses in the animal kingdom too. Forensics teams can measure paw prints to learn when and where species are travelling, use DNA samples to find out how many offspring a particular animal has and learn about their diet by analysing their droppings.

5 TOP FACTS
WHY CHICKENS?

On the pulse
1 The spots of the pox are said by some to look a little like chickpeas, which are extremely popular in Asian cuisine, but bear no relation to chickens at all.

Chicken children
2 As it is more likely to be contracted by the young than the old, the word 'chicken' comes from its reputation as a child's disease, rather than one from the bird.

Blame the hen
3 In the past, the virus was believed to have been caused by the farmyard fowl. It has since been found completely innocent of these charges though.

Cowardly disease
4 In Samuel Johnson's 1755 dictionary, the name is attributed to the fact that the disease is of minimal risk to the sufferer compared to similar diseases like smallpox.

Pecking order
5 Perhaps most bizarrely of all the explanations, the rashes have been described in the past as having looked like a chicken has repeatedly pecked at your skin!

DID YOU KNOW? *Pregnant women who contract chickenpox can even pass it on to their baby in the womb*

Understanding chickenpox

Discover the biology behind the infamous childhood ailment and why it never really goes away…

Chickenpox is a strain of the Varicella zoster virus, which many of us have experienced during our youth. Most prominent in children under ten, the virus is contracted through coughing and sneezing or transferred on shared objects, which makes schools a prime location.

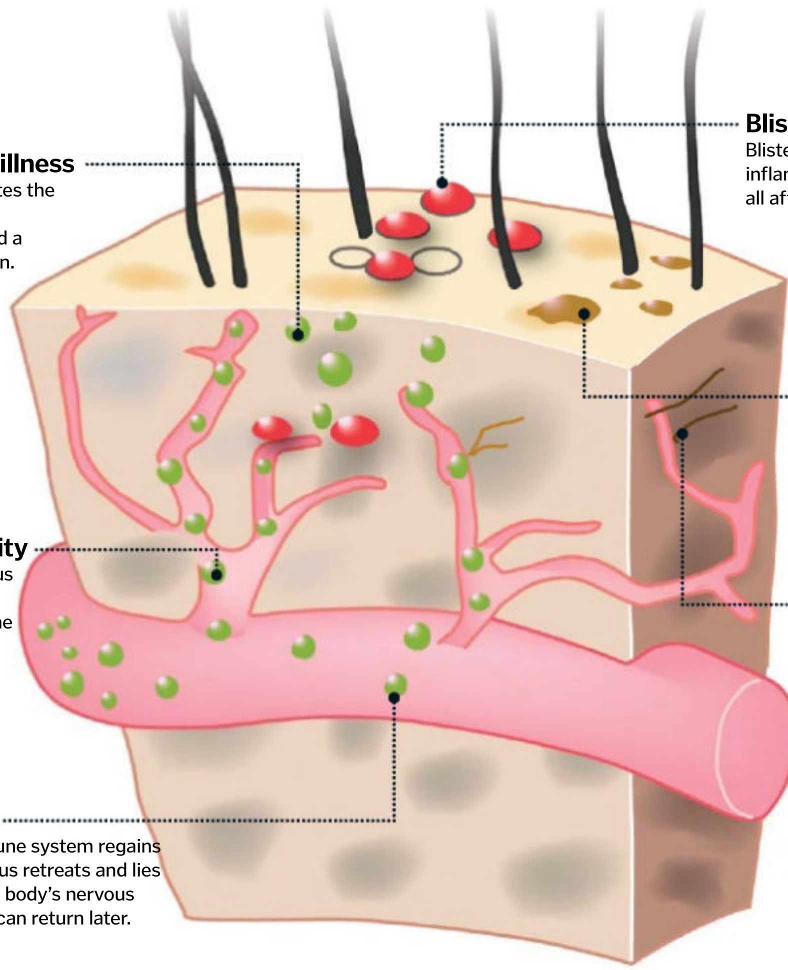
The most famous symptom is the appearance of small itchy red spots, which vary in size from 10-20 millimetres (0.4-0.8 inches) across. The extent can vary but in most cases they cover the face, arms, legs, stomach and back. These develop into fluid-filled blisters and are often accompanied by a fever. The blisters burst, scab over and fall off within a few days, but new waves of spots can emerge to replace them; it usually takes one to two weeks for the body to regain control. Chickenpox is rarely serious but it is important not to interfere with the scabs as infection can make it more severe.

A vaccine is only offered in extreme circumstances when an individual may have a weak immune system or be particularly vulnerable to the disease.

After the outbreak, chickenpox doesn't disappear entirely. The disease lies in a dormant state within the body as your immune system keeps it under wraps. The infection can break out again later and reappear as shingles. A rash builds up on a certain point of the body and the symptoms return, most commonly in people over 50. On average, three in every 1,000 people contract shingles in the UK each year.

When chickenpox strikes back…

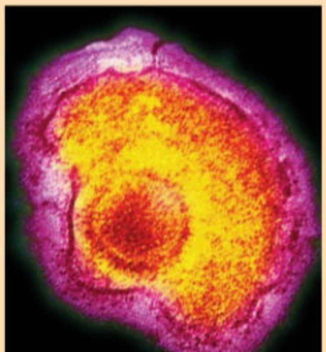
Get under the skin to see how shingles can catch the body unawares



Grown-up chickenpox

90 per cent of adults are immune if they've had the disease as a child but it still affects adults and teenagers. If you develop chickenpox at a later age, all the symptoms are more severe, with more chronic pain, headaches and sore throats; therefore, there is greater need for treatment, such as pain relief and soothing creams.

The disease tends to affect adults more dramatically as it can now mutate into a variety of other strains, such as shingles or, in extreme cases, lead to encephalitis, postherpetic neuralgia or pneumonia. However, the chances of this happening are only around ten per cent.

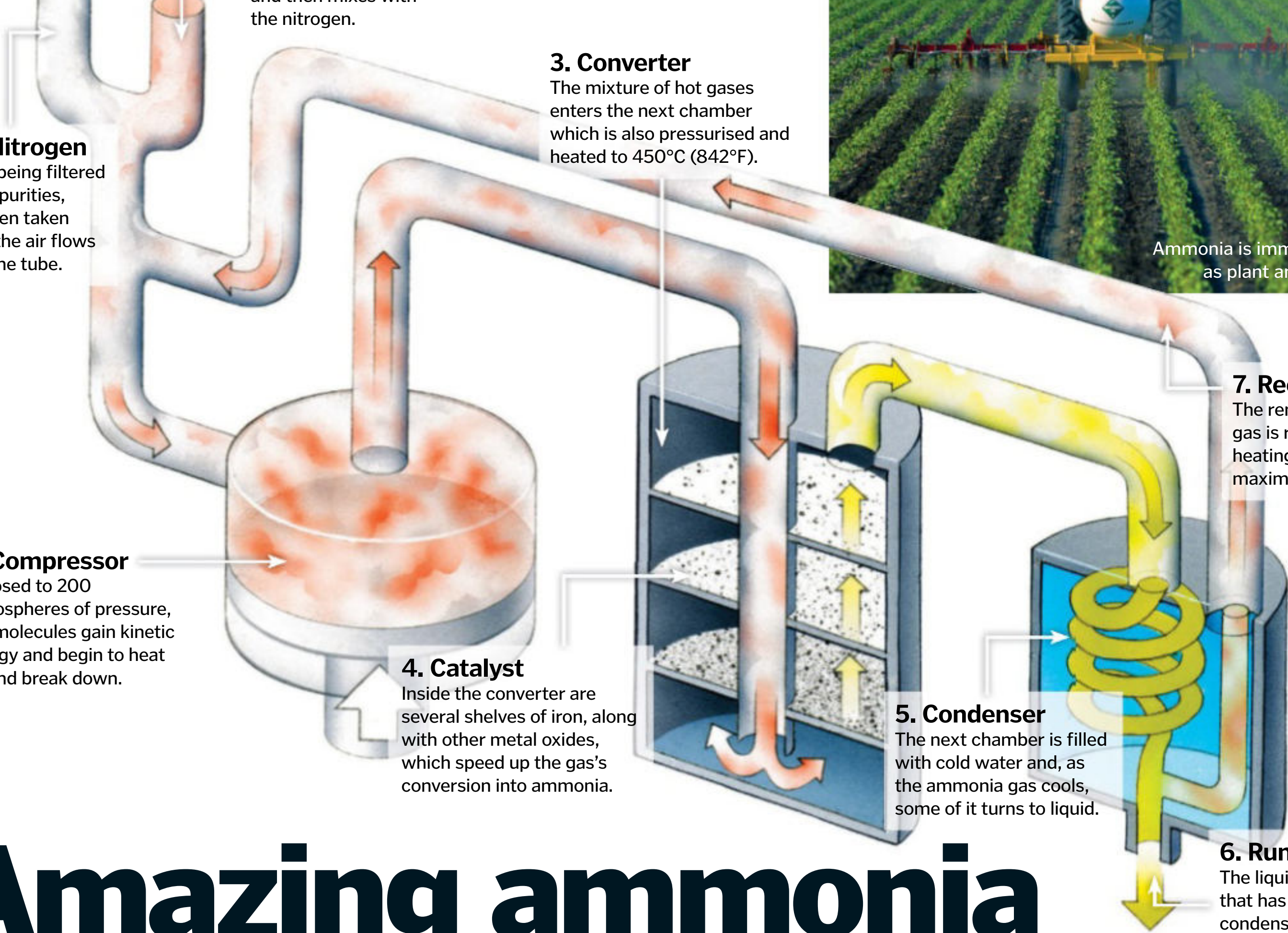


Deaths from chickenpox have reduced dramatically in the last 25 years

> *"Plants are able to absorb the reactive nitrogen atoms easily and use them in the composition of amino acids"*

How to make ammonia

The key stages behind the Haber-Bosch process




Ammonia is immensely valuable as plant and crop fertiliser

Amazing ammonia

Find out how we use this pungent chemical day to day

Ammonia is a compound gas that is most commonly used as a fertiliser, but also as a domestic cleaner and to make explosives, dyes and everyday synthetic fabrics, such as nylon.

The main method by which ammonia can be created artificially is the Haber-Bosch process during which nitrogen and hydrogen gas are combined. Nitrogen from the air and natural gas-derived hydrogen get combined in a 1:3 ratio ($N_2+3H_2 <=> 2NH_3$) at around 450 degrees Celsius (842 degrees Fahrenheit) while under 200 atmospheres of pressure, using a catalyst to speed up the reaction.

Once combined and cooled, around 15 per cent of the gas mix forms liquid ammonia. The remaining gases loop back into the system for it all to begin again, resulting in an impressive conversion rate of around 98 per cent.

Ammonia's primary use is as agricultural fertiliser. In its non-chemically produced state, ammonia is created when amino acids break down. When put into soil, plants are able to absorb the reactive nitrogen atoms easily and then use them in the composition of their own amino acids, which are required for growth and repair. Another lesser-known application of ammonia is as rocket fuel (see '3,2,1, blast off!').

Ammonia is also used in hair colouring to open out the cuticle, allowing the colours to seep deep into the hair cortex, but repeatedly doing this can dry hair out and damage it.

3, 2, 1, blast off!

Hydrazine is a chemical relative of ammonia. First created in 1889, it can be used to manufacture rocket fuel. It has since been replaced by unsymmetrical dimethylhydrazine (UDMH), but was one of the fuels used in the Apollo 11 mission to the Moon in 1969.

Hydrazine is created when an ammonia solution reacts with sodium hypochlorite, or when ammonia comes directly into contact with hypochlorite ions, creating chloramine. This then reacts with the remaining ammonia to produce hydrazine. This is known as the Raschig process. When hydrazine reacts with oxygen it burns intensely, producing steam and nitrogen as chemical by-products to propel the rocket.

What is the longest you can go without water?

A One day B Three days C 70 years

Answer:
Most experts agree three days is the longest a human can go without water. However, Indian Prahlad Jani has claimed he has gone without water for 70 years. The controversial practice is called 'breatharianism' and alleges the body can survive on sunlight alone.

DID YOU KNOW? *In isotonic dehydration we lose equal water to salt but with hypernatraemic dehydration we lose more water*

Dehydration and the body

Find out what happens inside us when we don't quench our thirst

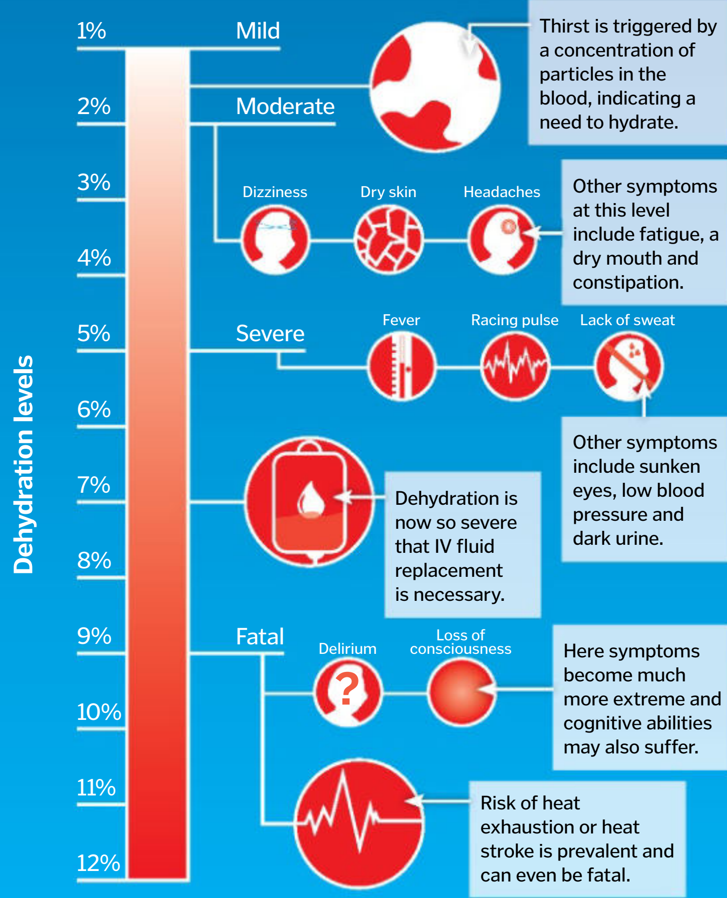
Just by breathing, sweating and urinating, the average person loses ten cups of water a day. With H_2O making up as much as 75 per cent of our body, dehydration is a frequent risk. Water is integral in maintaining our systems and it performs limitless functions. Lubricating the skin, flushing out waste and keeping blood pressure and cholesterol levels stable are just a few of its vital roles.

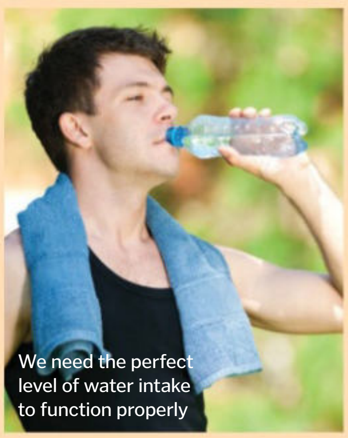
Essentially, dehydration strikes when your body takes in less fluid than it loses. The mineral balance in your body becomes upset with salt and sugar levels going haywire. Enzymatic activity is slowed, toxins accumulate more easily and even breathing can become more difficult as the lungs are having to work harder.

Babies and the elderly are most susceptible as their bodies are not as resilient as other age groups. It has long been recommended to have eight glasses of water or two litres (0.5 gallons) a day. More recent research is undecided, as both slightly less and slightly more have been considered healthy.

Dangers of dehydration

How does a lack of water vary from mild to fatal?





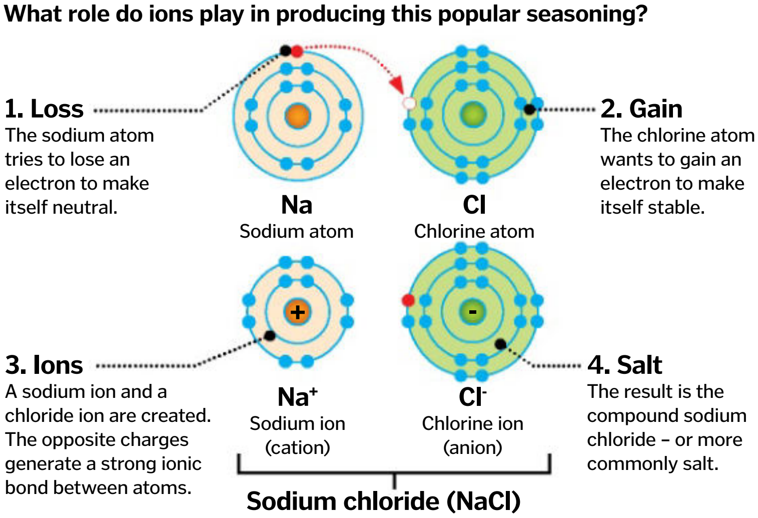
We need the perfect level of water intake to function properly

Too much H_2O?

Hydration is all about finding the perfect balance. Too much hydration can be harmful as well as too little; this is known as water intoxication. If too much liquid is in your body, nutrients such as electrolytes and sodium are diluted and the body suffers as a result. Your cells bloat and expand and can even burst, and it can be fatal if untreated. The best treatment is to take on IV fluids containing electrolytes. Water intoxication is just one type of hyponatraemia, which also includes excessive sweating and liver and kidney problems.

Salt in the making

What role do ions play in producing this popular seasoning?



Ions explained

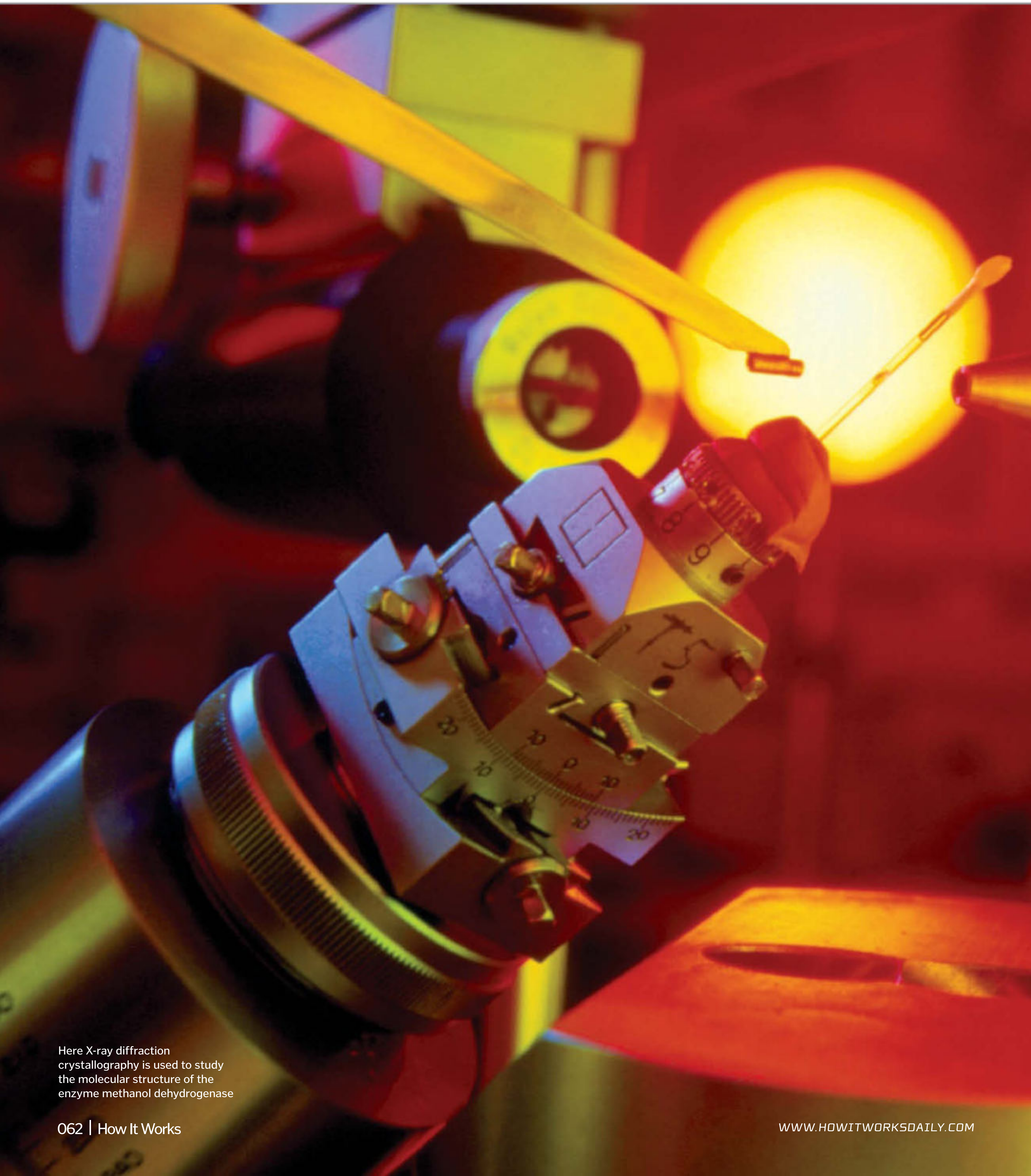
The electric science of charged atoms revealed

An ion is an atom or molecule that has an electric charge, which stems from an odd number of electrons. Extra electrons result in a negative charge (anion) while fewer result in a positive charge (cation). The process of atoms turning to ions is called ionisation and occurs between metals and nonmetals. Metal atoms become positive ions and nonmetal atoms become negative ions.

Common examples of ion-forming elements are sodium, chlorine and potassium. Sodium and potassium are metals while chlorine is a nonmetal.

Electrolysis can be used to separate ionic compounds back into their pure elements, where an electric current is passed through to divide the charged ions. This technique is especially useful for extracting precious metals, such as gold and silver, from their ores.

"The rise of crystallography has paved the way to understanding atomic structure and bonding"



Here X-ray diffraction crystallography is used to study the molecular structure of the enzyme methanol dehydrogenase

KEY DATES
CRYSTAL HISTORY

1850 Auguste Bravais discovers the 'Bravais Lattice', describing the arrangement of crystal atoms for the first time.

1895 Wilhelm Röntgen discovers X-rays after experimenting with cathode rays.

1905 CG Barkla first polarises X-rays, opening up the ways we could use this form of radiation.

1914-1915 Max von Laue and the Braggs win Nobel prizes for developing earlier theories of diffraction and structure.

1964 Dorothy Crowfoot Hodgkin wins a Nobel prize for determining the crystal structures of penicillin and vitamin B12.

DID YOU KNOW? Von Laue was asked by the Nazis to work on a nuclear weapons programme, but he refused

Crystals under the microscope

2014 is the year of crystallography, but what is it?

Crystallography is the analysis of crystals, used to increase our understanding of internal atomic structures – not just of minerals but of any substance which can be crystallised.

The practice is centred on the unique geometry of a crystal. First theorised by French physicist Auguste Bravais, all of a substance's angles are measured to find a crystal or lattice system. Co-ordinates are plotted to determine any symmetry, which can then define the atomic structure.

X-ray crystallography was popularised by German physicist Max von Laue in 1912, who showed crystals could be diffracted by this method. Atoms within the crystal diffract the X-rays and the angles of the deflection are measured. Scientists can then map a material's inner structure in great detail.

This technique can be used to determine the structure of organic substances such as proteins and DNA, as well as vitamins, alloys and other composite materials.

The rise of crystallography has paved the way to understanding atomic structure and bonding across many scientific fields like never before, though this technique remains relatively unknown. This is why the UN has declared 2014 as the International Year of Crystallography in order to raise its profile.

The origins of X-ray crystallography

The practice is thought to have originated from the work of Max von Laue. The German physicist worked in universities across the country, under the guidance of famous scientists Max Planck and Albert Einstein. He discovered the diffraction of X-rays through the atoms of a crystal in 1912. His results were developed with the help of physicists Paul Knipping and Walter Friedrich and demonstrated the period arrays of atoms in crystals.

Englishman William Bragg and his son Lawrence built on Von Laue's work to create an X-ray spectrometer that analysed the molecular structure of crystals, showing the relative positions of atoms in crystals. Von Laue and the Braggs received the Nobel Prize for Physics in 1914 and 1915, respectively.

Mapping out a protein

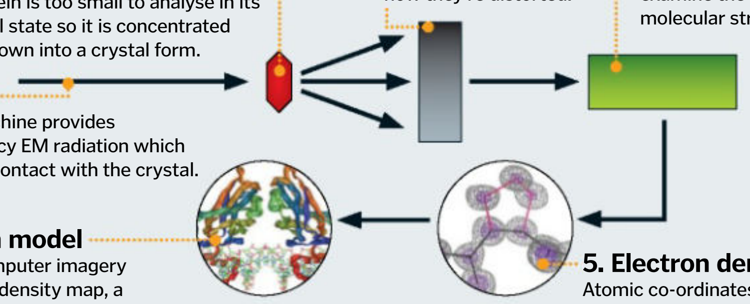
How crystallography unlocks our microbiology

1. X-rays
An X-ray machine provides high-frequency EM radiation which diffracts on contact with the crystal.

2. Protein crystal
A protein is too small to analyse in its natural state so it is concentrated and grown into a crystal form.

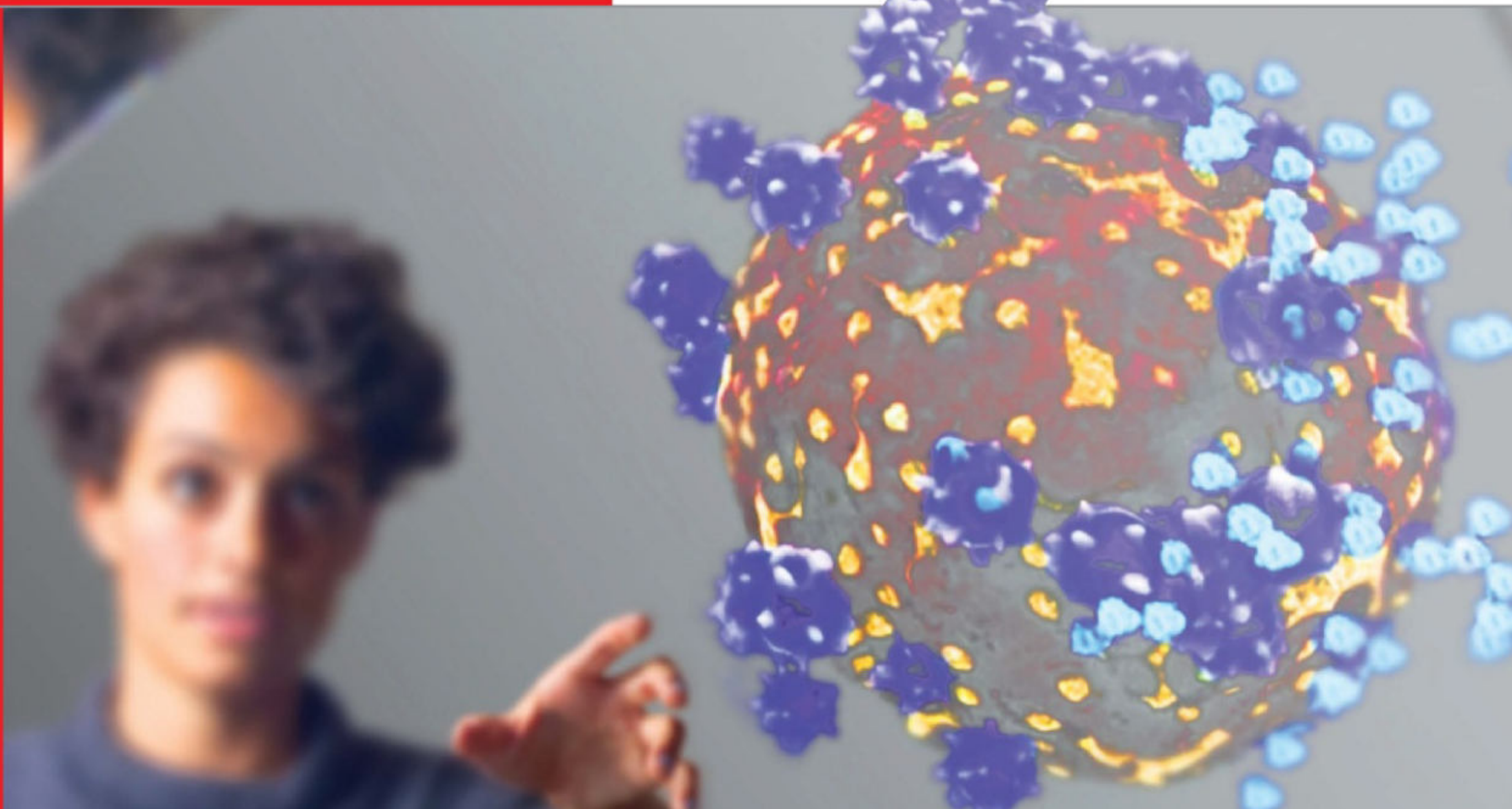
3. Catching some rays
A detector measures the properties of the rays and how they're distorted.

4. Make an image
The data is then uploaded to a computer so crystallographers can examine the crystal's molecular structure.



5. Electron density map
Atomic co-ordinates are drawn up and a high-resolution map is created showing the newfound diffraction pattern.

6. Protein model
From the computer imagery and electron density map, a model can be created that displays the protein's atomic structure.



Making holograms

How cutting-edge technology captures 3D objects and re-creates them with light in ever-more realistic ways

The principle of making a hologram is similar to recording an orchestra in surround sound – once the sound has been recorded, the orchestra can stop playing and the sound can be re-created again and again without any instruments.

Instead of recording audio, a hologram stores the interference pattern generated by light scattered by an object. This allows that light scatter to be reproduced later, giving the illusion the object is still there.

Capturing a hologram requires a laser light source – most often a red helium-neon laser. The light is divided by a beam splitter and each new beam travels a separate path to the holographic recording plate. The first beam – the object beam – travels to the object itself, while the second goes to a recording plate as a reference to obtain the interference pattern.

Before they reach their targets, each beam travels through a lens. Unlike the lens of a camera, the lenses of a holographic recorder are not designed to focus light, but instead spread it out. As the object beam strikes the object, light is reflected and refracted, some of it in the direction of the holographic recording plate. As the object beam reaches the plate, it collides with the reference beam, generating an interference pattern. Interference is recorded using fine grains of photosensitive chemicals, similar to those used in photography.

In essence, the exposed holographic plate is more like a CD than a photographic negative. The stored information cannot be deciphered with the naked eye, instead appearing as a series of bumps and wavy lines. In order to actually view a hologram, a light source must be applied to the film.

There are two main types of hologram, with each viewed in a different way. To look at a transmission hologram, a monochromatic light is passed through the film, producing a floating three-dimensional image of a single colour (most often green). Alternatively, reflection holograms, like those found on bank notes, bounce back light and can be multicoloured.

The process of creating a hologram is incredibly light-sensitive, much like traditional photography, so holographic recording is done in a darkroom. Due to the red colour of most holography lasers, traditional red darkroom lights damage the holographic plates, so green or blue-green lights are used instead.

Holography is also much more sensitive to environmental conditions than photography; so much information is packed into such a small space that even minute deviations in the lasers can ruin the hologram. Vibrations in the floor, in the air from body movement or even as people breathe can disrupt the delicate recording process.

Despite the difficulties in creating holograms, the storage capacity they provide is quite

5 TOP FACTS
HOLLYWOOD HOLOS

Iron Man

1 In the live action *Iron Man* films, starring Robert Downey Jr, eccentric entrepreneur Tony Stark uses holographic projection to manipulate three-dimensional prototypes.

Star Wars

2 In the *Star Wars* universe, holography is used as a form of video communication. They are monochrome and visible from all sides, much like real holograms existing today.

Minority Report

3 In Steven Spielberg's 2002 thriller, Tom Cruise controls a holographic heads-up display using motion sensors on his gloved hands to help prevent future crimes.

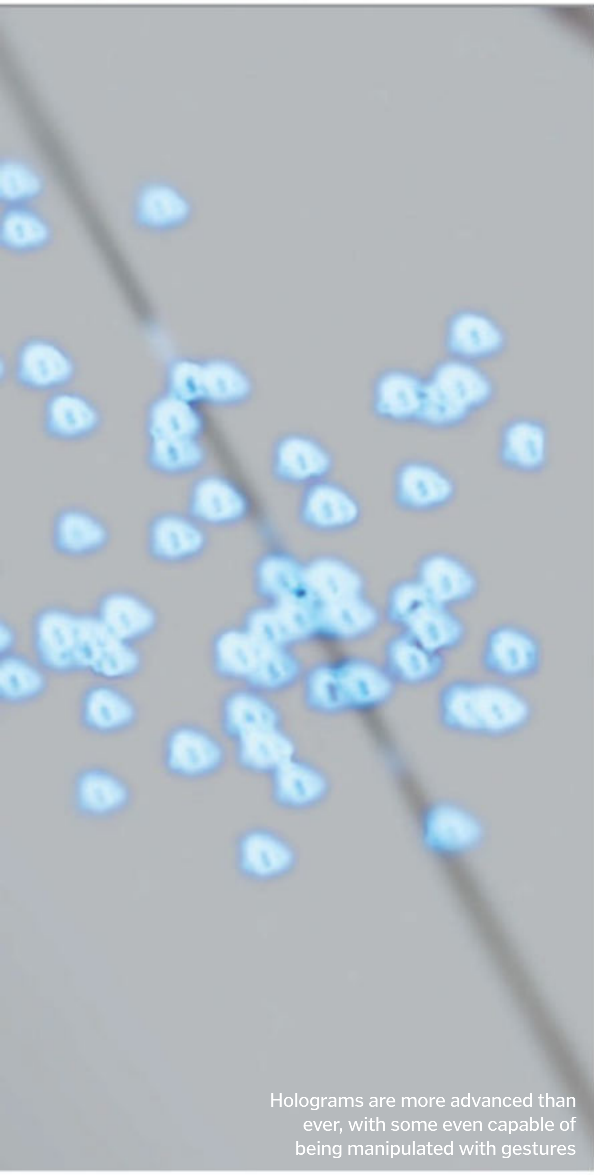
Vanilla Sky

4 A holographic projection of jazz musician John Coltrane appears in the apartment of Tom Cruise during one scene of the 2001 futuristic drama *Vanilla Sky.*

Back To The Future Pt II

5 This 1989 film predicted that by 2015, holographic displays would be used to advertise films like *Jaws 19*. Now in 2014, a similar real-life display advertised *Captain America 2*.

DID YOU KNOW? Some physicists hypothesise that our universe is actually a hologram, while the 'true' universe is two-dimensional



Holograms are more advanced than ever, with some even capable of being manipulated with gestures

simply incredible. Holographic images are truly three-dimensional and can be viewed from all angles. The images are also scalable and holograms made with one wavelength can be viewed with another – the size of the resulting hologram scaling with the wavelength of viewing light. In theory, this means that holograms of extremely small structures, down to the molecular scale, could be created using X-rays and then viewed using visible light, although this is yet to be done.

One of the major challenges in holography is producing moving holograms; much like camera film, when conventional holographic recording plates are exposed, the image is fixed. Scottish company Holoxica has developed a holographic screen capable of storing prerecorded holographic images. The screen is illuminated from behind, generating a holographic projection above. The screen can switch between the prerecorded images to

Waking the dead

In 2012, the audience at music festival Coachella were surprised and amazed when the rappers Snoop Dogg and Dr Dre were joined on stage by the musician Tupac Shakur, who died in 1996.

Using a combination of video footage, CGI, body doubles and motion capture technology, it is now possible to digitally resurrect deceased performers, and bring them back to the stage. This illusion was created using the Musion Eyeliner, and we spoke to Liz Berry, director at Hologramica, about how these incredible illusions are produced and projected.

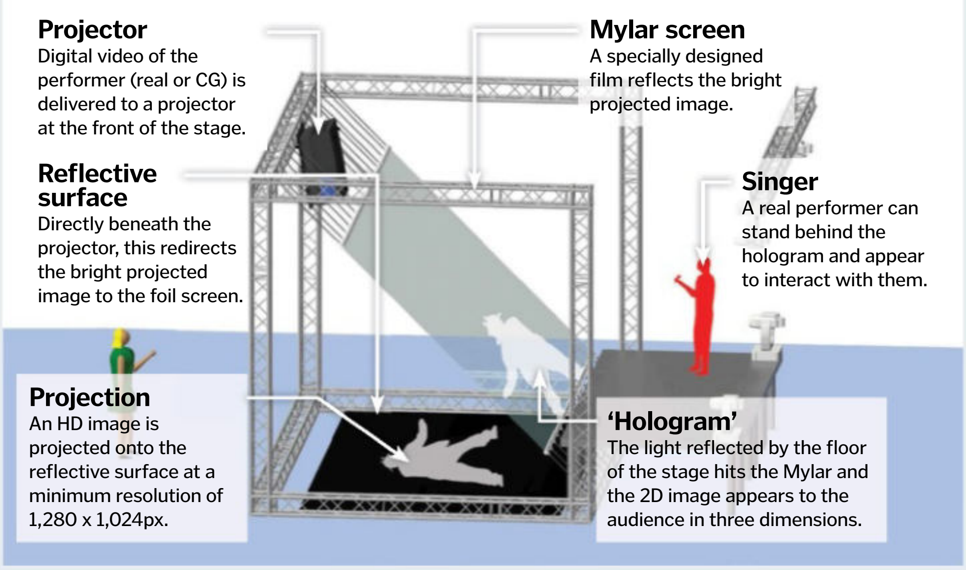
"You need a continuous full body shot of the subject(s) being projected as HD video. This can be achieved by doing a film shoot, or you may be lucky and find existing footage for someone you can't film. Alternatively you can use CGI. Sometimes it's a mix. So, for example, Frank Sinatra was created with both old footage and new film, using CGI to combine the two as a lifelike hologram.

"Every element of the presentation has to feel authentic. The lighting has to be right, and that's the single most important factor. But for me it has to start with the design of the stage itself to give you the most effective and elegant way of deploying physically bulky equipment that has to be placed accurately. Some considerations are purely technical, others are creative and take a good image and enhance it by finding ways to blend the real and the virtual seamlessly."

Snoop Dogg sharing the stage with a hologram of deceased rapper Tupac

Digital resurrection tech

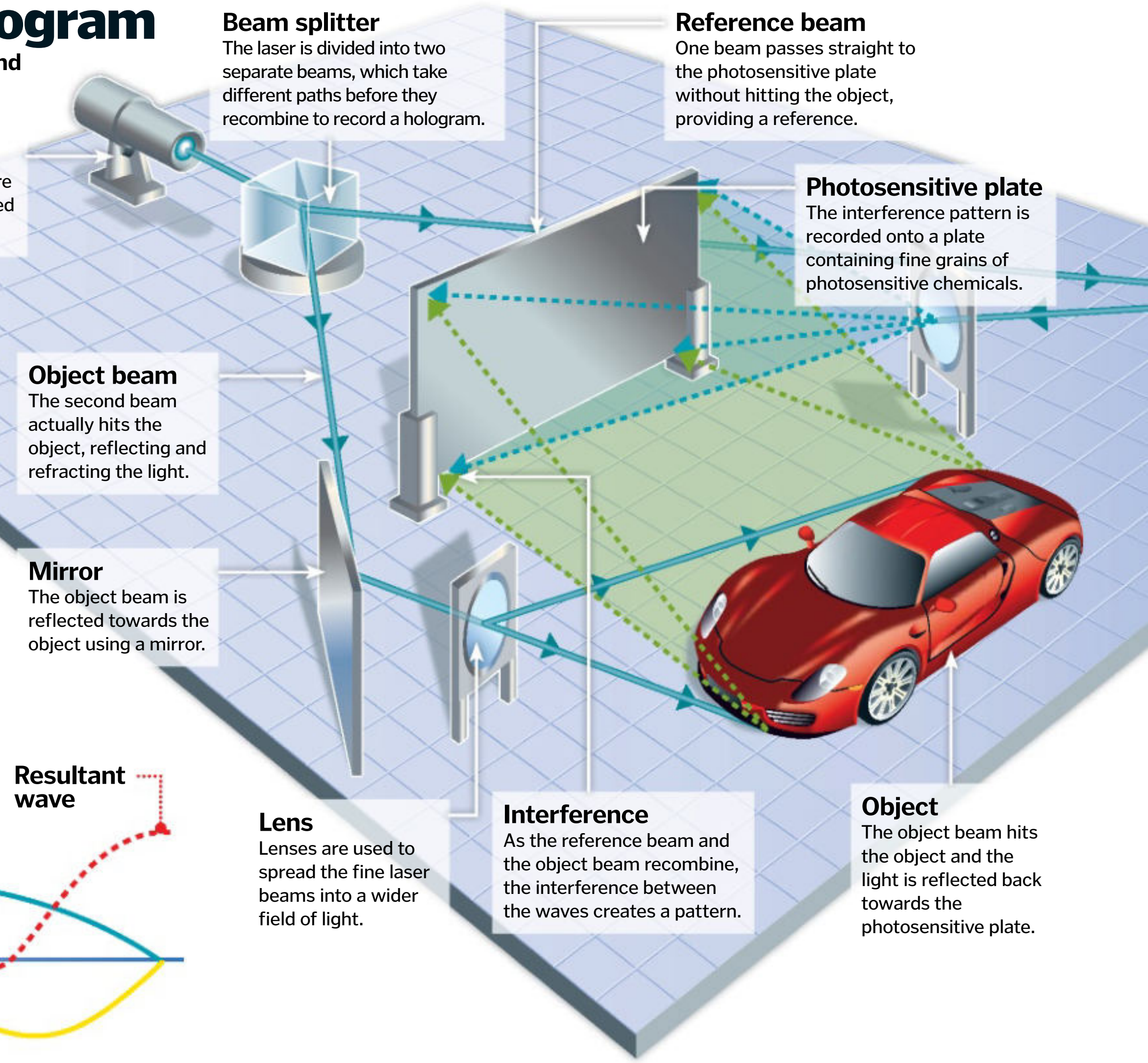
Using a 21st-century version of a Victorian theatre trick, singers can perform to millions from beyond the grave



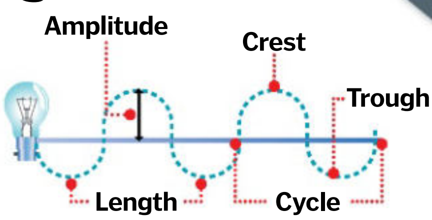
"Doctors are already using interactive holograms to help perform surgery by re-creating models of organs"

How to make a hologram

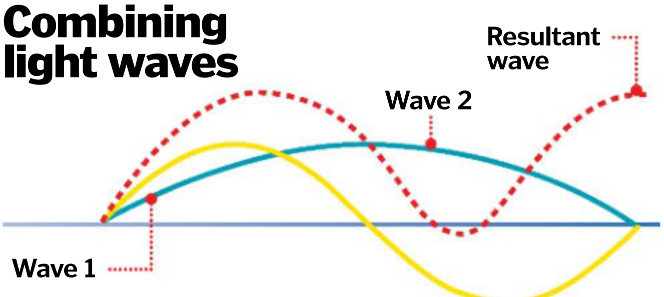
The science behind recording a hologram and re-creating it is surprisingly simple



How does light move?



Combining light waves



change the visible projection. By using collections of simpler interference patterns more complex images can be created, a bit like pixels forming an image on an LCD screen.

True moving holograms might not be here yet, but companies like Musion, AV Concepts and Hologramica are using advanced digital media techniques to create realistic, life-size 3D projections that are the next best thing. Between them, they have given form to the animated band Gorillaz, staged a piano battle between a musician and his holographic double, and even brought musicians back from the dead (see the 'Waking the dead' boxout).

We spoke to Liz Berry, the director of 3D holographic projection company Hologramica, about the secret behind these incredible stage shows – an old illusion known as Pepper's Ghost: "Pepper's Ghost was originally used in Victorian theatres to make supernatural effects. They would place a lit performer out of the audience's view and position a piece of glass between the performer and the audience. The viewers wouldn't know they were viewing the stage through the angled glass because it's transparent, and the lit actor's reflection would appear as a ghostly apparition. The modern take uses bright HD video and the glass is now a specially developed foil. The image is projected onto a concealed screen on the floor so you only see the reflection in the foil, and voila!

"So the holographic illusion is basically HD video in 2D. Although what we create isn't technically a hologram in the truest sense, it's become popularly known as that. I sometimes think we should run a competition to come up with a better name, but I guess we have to stick with hologram for now!"

This tech has been miniaturised by British company Beagle Media, which has developed one of the most advanced hologram players – Holo. Using a Mac Mini and four 140-centimetre (55-inch) Samsung panels, a 2D image is projected to appear in three dimensions. Not only that, but motion sensors allow the object to be manipulated in real-time with gestures.

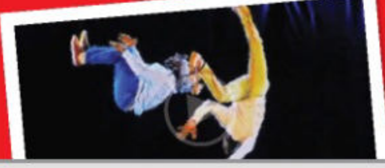
Illusion techniques are also being used to explore the development of touchable holograms. The mirage toy is a classic illusion; an object is placed on top of a concave mirror, and a second mirror is placed on top. The reflection of the light inside the mirrored chamber focuses the image just above an opening at the top, making it appear as though the object is sitting outside of it.

Researchers at the University of Tokyo are using it as a tool to develop holograms we can interact with. Hand movements are tracked using infrared sensors from Nintendo Wii remotes, while airborne ultrasound signals create tiny pressure waves that mimic the sensation of touch. Microsoft is developing similar technology with Kinect.

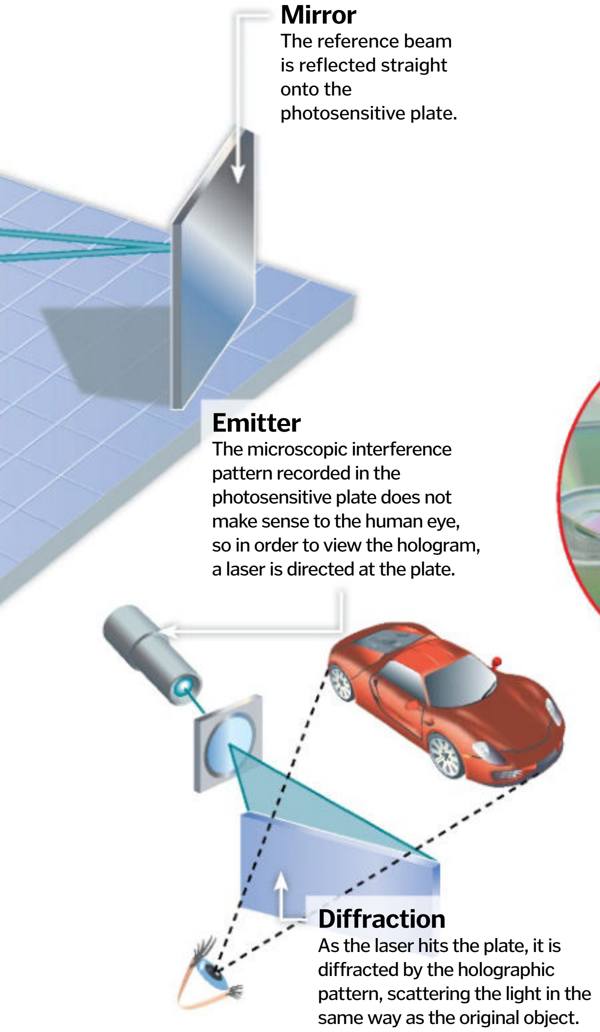
AMAZING VIDEO!
SCAN THE QR CODE FOR A QUICK LINK

Take a look at the Musion Eyeliner in action

www.howitworksdaily.com



DID YOU KNOW? *Leia Display Systems take advantage of light scattering to create 3D projections on sheets of water vapour*



The potential for these kinds of technology is vast. Not only can holographic images be used for entertainment, art and education, but the potential applications in medical science, technology design and augmented reality are huge. Doctors in Israel are already using interactive holograms to help perform surgery by re-creating real-time models of organs during operations, while research at the Human Media Lab at Queen's University in Ontario, Canada, is at the early stages of designing a 3D version of Skype (pictured right).

True moving holograms might currently look like LCD screens from the 1980s, but look at where those screens are now. For Hologramica, it's all about achieving the impossible: "[We can] make cars float, turn ballerinas into crystal swans, and do things on stage that you can't do by any other means; people engage emotionally with these images as well as just looking at them. Seeing is believing."

The man behind the hologram

Hungarian-British engineer Dennis Gabor was awarded the Nobel Prize for Physics in 1971 for the invention of the holographic method. He realised that optical imaging only records the amplitude of waves, not the phase, and that if you recorded both, a three-dimensional image could be captured. Despite conceiving his initial ideas in 1947, the laser was not invented until 1960 and it was not until 1964 that the first hologram was made.

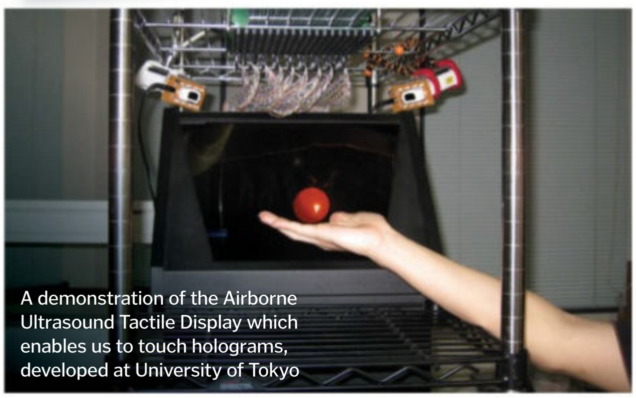
5 reasons why holograms beat CDs hands down

- ✔ Higher storage capacity
- ✔ Faster data transfer
- ✔ Long-term stability
- ✔ Unaffected by magnetic fields
- ✔ Smaller size

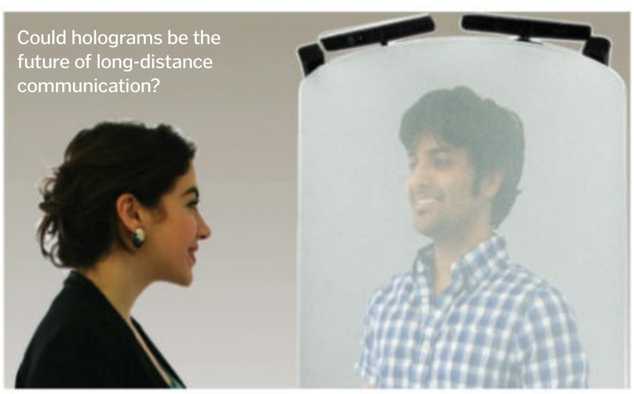
The future of data storage

Holograms aren't just useful for displaying 3D images in art galleries and at music festivals; they could also be the next big thing in data storage.

Conventional storage methods, like CDs and DVDs, can only store information in two dimensions, can only be accessed from one angle, and must be read in series as the disk spins. By representing binary information visually, as clear and black boxes, it is possible to store it in hologram form. A 3D storage hologram could be read, and written to, from all angles, and different areas could be accessed in parallel, allowing compact storage and superfast replay.



A demonstration of the Airborne Ultrasound Tactile Display which enables us to touch holograms, developed at University of Tokyo



Could holograms be the future of long-distance communication?

Everyday holograms

1 Security hologram

Perhaps the most widely recognised and are used to mark items like credit cards, bank notes and passports. The images are hard to replicate and are used to prevent counterfeiting and fraud.

2 Museum archiving

Holographic records of museum artefacts not only enable them to be shared worldwide, but they also allow curators to monitor any deterioration in the condition of their collection. It also serves as evidence in case an item is lost or stolen.

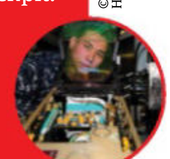
3 Medical imaging

Instead of viewing a simulated 3D image on a screen, doctors are finding it increasingly useful to convert digital images taken by medical scanners, including MRI and ultrasound, into holograms.

4 Barcode scanners

Holographic scanners use laser beams to explore barcodes. Each beam follows a different path, generating a three-dimensional image of the barcode, allowing it to be read from any direction, even if the scanner is facing the side of the packet.

5 Heads-up display



Holographic HUDs effectively superimpose a navigational display onto a pilot's view out of the cockpit. Advances in hologram technology will soon enable HUDs to be incorporated into the glass of car mirrors too.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Fireplace inserts
1 One way to make your chimney more efficient are inserts that use steel to retain heat. In some instances they have an attached blower with vents to actively push hot air back in.

Damper
2 Plays a role whether opened or closed. When open, it controls airflow and efficiency, closed it stops warmer air from escaping and cuts off air if a chimney fire starts.

Fireback
3 In the same vein as an insert, its thick metal body holds heat and it is most effective in a wood fire as the metal radiates heat to its immediate surroundings.

Electric heater
4 This mechanism generates heat by pulling air from the room, warming it and sending it back. It works hard when the chimney needs it and eases off when it doesn't.

Glass doors
5 Although quite a big undertaking to install, these work by reducing the area that needs heating and radiating heat. They also double up as a safety feature to block sparks.

DID YOU KNOW? *The world's tallest chimney is in the Ekibastuz power station in Kazakhstan, at 419.7m (1,377ft) high*

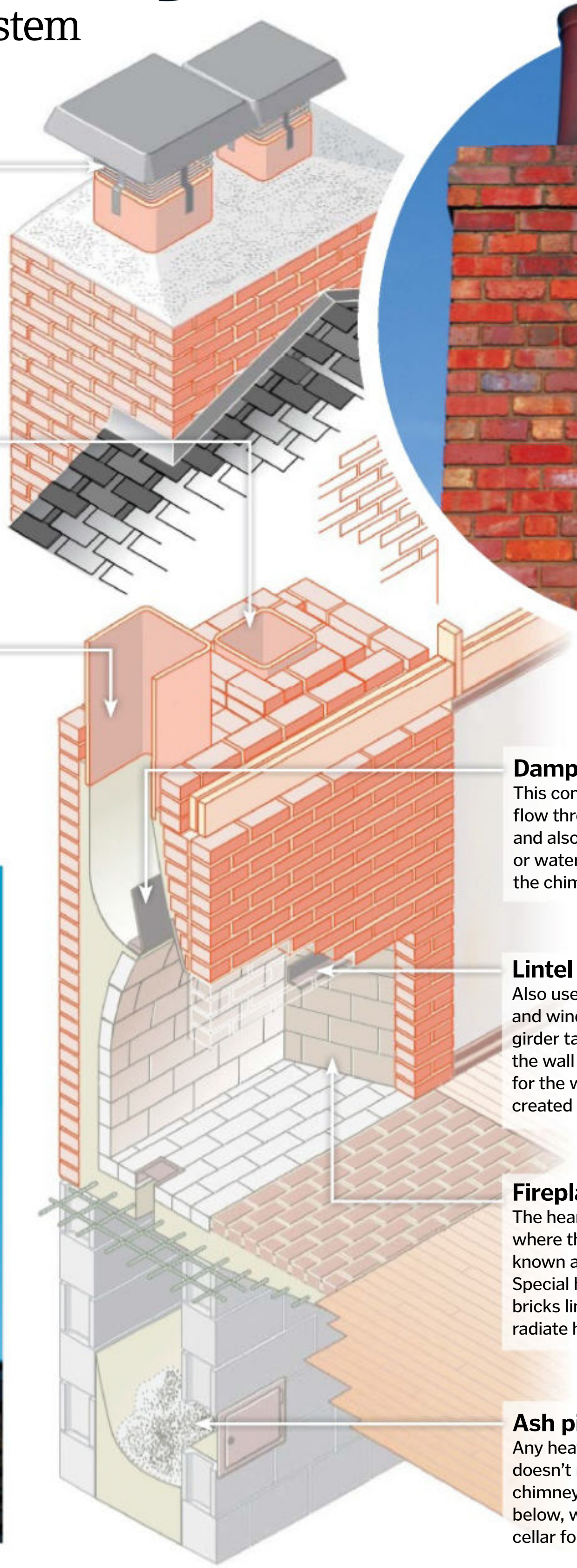
How do chimneys work?

Inside the classic household heating system

The fact that hot air is less dense than cold and so rises is vital to the workings of a chimney. In order to vent fumes out of our homes, they rely on a number of scientific principles to work effectively. Thanks to convection currents, pressure differences help fluids – in this case waste gases – move from the fireplace to the roof. This is known as the Venturi effect. Think of the hot fumes as water in a hosepipe. When the tap is turned on, water being forced through the narrow tube increases its speed; the same applies in a chimney.

The stack effect also helps speed up the process and works when surrounding cold air is denser than the hot air inside. This ensures that the hotter air always rises. Taller chimneys are more efficient as a higher column of air can build up; around 4.6 metres (15 feet) is considered an ideal height.

On a wider scale than the chimney, every house contains a neutral pressure plane (NPP). Air pressure above this level is higher than outside (positive) and tries to force its way out, while everything below is negative, so air is drawn in. By putting chimneys on the roof we ensure the exit point is as far above the NPP as possible so smoke doesn't sink back into the room, though sometimes high winds counteract this pressure differential.



On the roof
Vents raised off the roof emit the smoke away from the building, while chimney caps stop water, birds or other large debris getting in.

Flue #2
A second flue deals with fumes from the boiler or another fireplace. Dividing the flues helps to reduce creosote buildup.

Flue #1
Smoke and hot air naturally travel upwards from the fireplace. Flue efficiency is increased by the Venturi effect and draught.

Damper
This controls air and heat flow through the chimney and also blocks any wind or water that gets past the chimney crown.

Lintel
Also used above doors and windows, this metal girder takes the load of the wall to compensate for the weak point created by the fireplace.

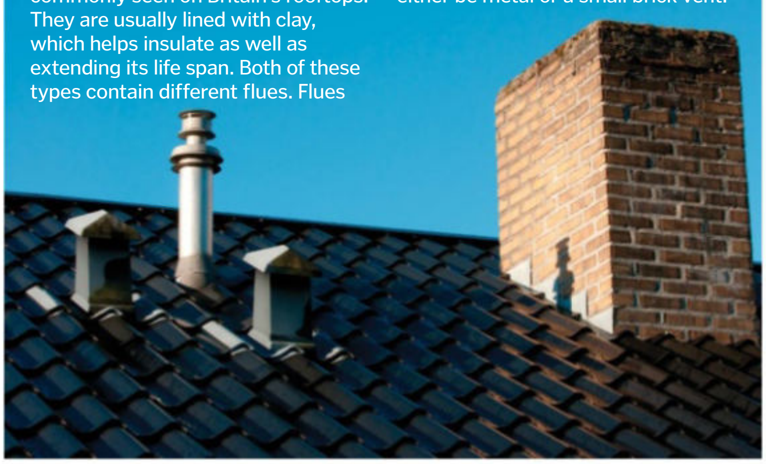
Fireplace
The heart of the fireplace where the fuel burns is known as the firebox. Special heat-resistant fire bricks line the sides to radiate heat into a room.

Ash pit
Any heavy soot which doesn't rise up the chimney sinks to a cavity below, with a door in the cellar for cleaning it out.

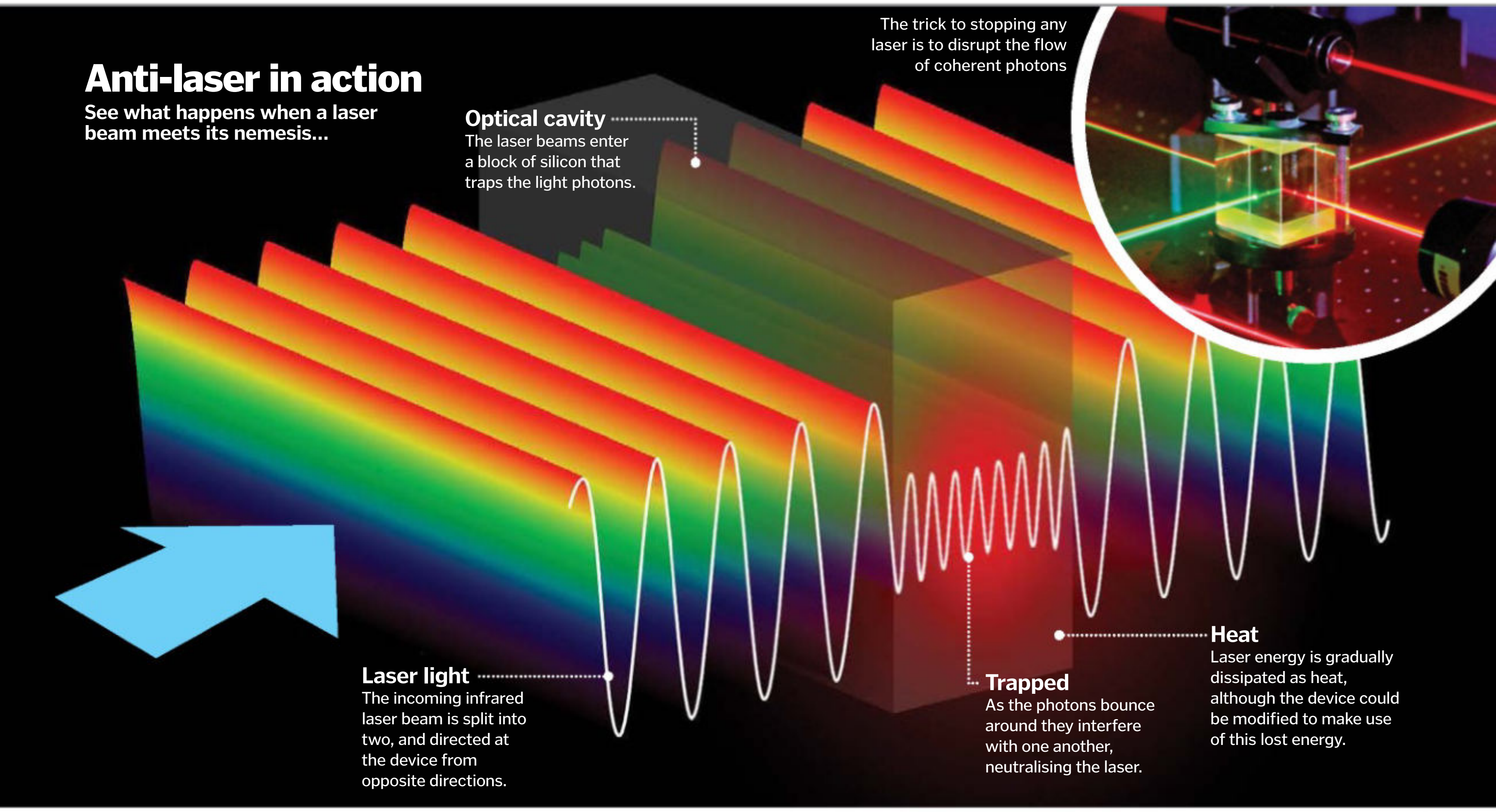
Chimneys big and small

Chimneys come in all shapes and sizes. Metal variations are quick to install and have push-fit joining so are more versatile and adaptable than their brick equivalents. Made of stainless steel, they are most suitable for coal and wood fires.

Brick chimneys are the type most commonly seen on Britain's rooftops. They are usually lined with clay, which helps insulate as well as extending its life span. Both of these types contain different flues. Flues help retain heat and expel toxic gases. Masonry versions usually have what is known as 'class one.' This is a basic system that relies on the natural rising of the hot air to work. However, the steel variety uses a 'class two', which is a more complex series of pipes. These can either be metal or a small brick vent.



"As the two beams bounce around inside the silicon, they lose energy as they cancel each other out"



Going inside an anti-laser

The tiny device that can stop a laser in its tracks

Faced with the puzzle of creating a device that could absorb laser energy, researchers at Yale looked at how laser light is produced and simply reversed the process. What they created in 2011 was the first anti-laser, or coherent perfect absorber (CPA).

Conventional lasers work by stimulating atoms in what's called a gain material. As these excited atoms drop back down to a less excited state, they emit photons with the same wavelength, creating light waves that are in step. Inside the laser amplification cavity, mirrors bounce these photons back and forth, causing excited atoms to emit photons of exactly the same wavelength. The result is a huge number of photons with the same frequency and direction, creating a focused beam of intense light energy.

The anti-laser demonstrated by Yale took this basic setup and switched it around. First a laser beam is split into two, with one of the two resulting beams being modified so it is out of step with its counterpart. The two incoming laser beams are directed at a small slab of silicon. The surface of the silicon acts as a one-way trapdoor, allowing the light to enter but not escape. As the two beams bounce around inside the silicon, they gradually lose energy as they cancel each other out through interference. Although the existing prototype can absorb 99.4 per cent of light, in theory it could be optimised to absorb 99.99 per cent.

More generally, the idea of reversing the process of laser light production by different materials could be used to investigate how those materials absorb light.

Developing anti-lasers

We asked A Douglas Stone, professor of Applied Physics at Yale University, for his take on the anti-laser technology he developed

What's so special about an anti-laser?
ADS: We realised that the strength of the anti-laser was that if you hit an opaque medium with exactly the right pattern of light then it would penetrate the medium and be absorbed. This is a totally new principle.

What applications does this have?
ADS: Suppose I want to know what's happening inside a solar cell. Depending on where in the cell the light is absorbed, the cell's efficiency at collecting energy varies. We can focus light deep within the cell to see how that changes things. If you're trying to perfect solar cells it's very exciting, although it might not resonate with the public just yet!

So there aren't any direct defence applications for anti-lasers?
ADS: When our research was published a lot of people thought it was somehow a defence against laser [weapons]. A mirror is a better defence – it's easier to get a laser to bounce off something than to try and absorb it. What we've developed is a selective absorption technique.

5 TOP FACTS
TOP POWER TOOLS

Sanders & planers
1 Used primarily on wood, these devices transform rough lumber into panels. A planer prepares the surface for use while a sander finishes and polishes it.

Electric screwdriver
2 Essentially just an automatic version of the classic tool, it is more powerful, requires less manual labour and is more precise than the standard.

Angle grinder
3 Driven by either electricity, petrol or compressed air, this power tool is used to grind, carve and cut into hard surfaces. It sure beats the average chisel!

Power saw
4 Used for cutting up boards of wood, this smaller sibling of the chainsaw can be used to help build tables as well as most other domestic furniture.

Staple gun
5 Another DIY 'gun', they range from heavy-duty electric versions for roofing and flooring to more lightweight manual types used for frames and upholstery.

DID YOU KNOW? *Nails are propelled out of nail guns at speeds of up to 427m (1,400ft) per second!*

How nail guns work

Meet the nail-slinging power tool putting hammers out of business

Used to drive nails into walls and other surfaces, the nail gun is an automated rival to the manual hammer in many areas of construction and manufacture. Its ability to launch nails at high speed and with relative ease makes the simple hammer seem pretty primitive by comparison.

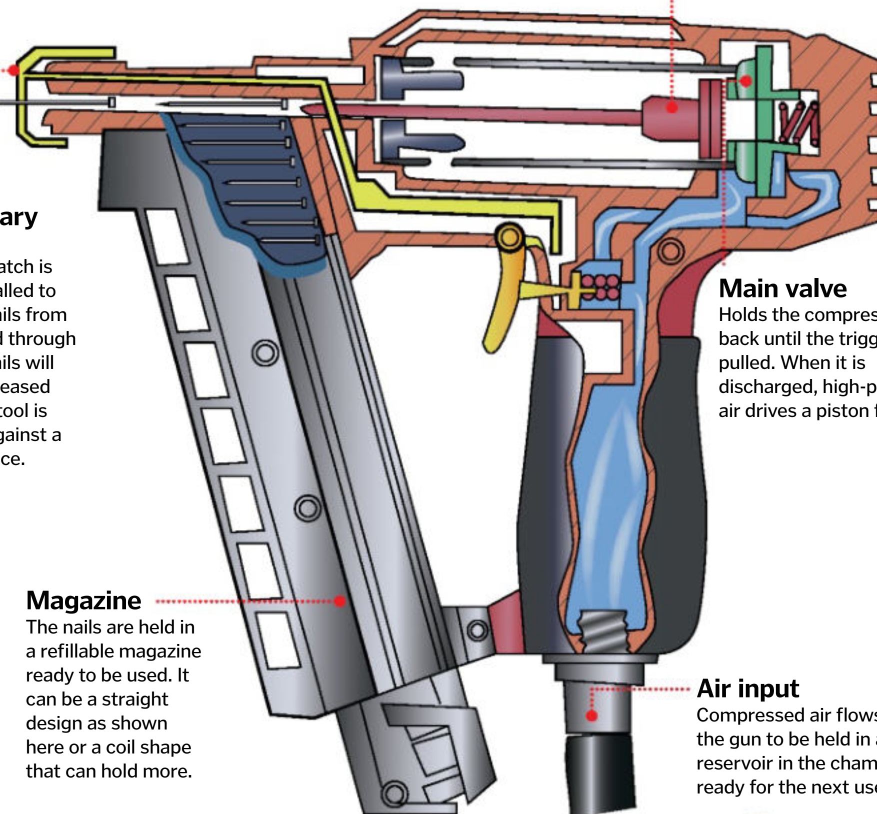
First invented in the 1950s, today there are a range of different nail guns on the market. The most basic is the spring-loaded design. This variation holds one nail at a time and uses a coiled spring to deliver the nail into the desired surface upon the press of the trigger.

Another type is the solenoid – or electromagnetic – nail gun. In this case, the piston is made from a magnetic material, which is either forced out of or drawn into the gun, depending on which way the magnetic current is flowing. Solenoids are more reliable than the spring-loaded design but have a lot less power than pneumatic nail guns (see annotation).

Using compressed air generated from pistons, a pneumatic nail gun can penetrate even the hardest surfaces. Another variation is the combustion nail gun, which ignites flammable gas mixed with air to create a small explosion (like those that power your car engine) forcing the nail out of the chamber. However, its sheer power and air compressor attachment make its uses more limited than other designs.

Inside a pneumatic gun

Discover the inner workings of an air-powered nail gun



Piston
The piston shoots forward and propels the nails fed from a magazine in front.

Secondary trigger
A safety catch is often installed to prevent nails from being fired through thin air. Nails will only be released when the tool is pressed against a solid surface.

Main valve
Holds the compressed air back until the trigger is pulled. When it is discharged, high-pressure air drives a piston forward.

Magazine
The nails are held in a refillable magazine ready to be used. It can be a straight design as shown here or a coil shape that can hold more.

Air input
Compressed air flows into the gun to be held in a reservoir in the chamber ready for the next use.

Nail guns can save a lot of time and energy compared to hammering

Origins of the nail gun

The tool was first invented in the 1950s by three US construction workers – Marvin Hirsch, John Ollig and Reuben Miller – who are thought to have based their idea on the mechanisms of WWII machine guns.

Veterans of the war, they devised the product in a garage and displayed their idea to the Independent Nail Company. Impressed by their invention, the company offered the trio $25,000. They initially declined the offer with a view to starting up their own business, but after running into financial difficulties, the rights were eventually purchased by another firm, Bostitch. Over the following decades, it evolved into the widely used power tool we know today.

"Underneath these are 15 rollerskate-type wheels that run on grooves, all pushed along by two diesel motors"

How do buildings rotate?

Explore the panoramic world of structures that like to get in a spin as we uncover the remarkable engineering that powers them

A new breed of architects has decided to make great views and sunbathed living rooms a permanent fixture by creating rotating houses. One of the first spinning homes was the Villa Girasole in Marcellise, Italy. This L-shaped residence sits on a circular base 44 metres (144 feet) in diameter, with three circular rails supporting it. Underneath these are 15 rollerskate-type wheels that run on grooves, all pushed along by two diesel motors attached to a central tower that pulls the building on a 360-degree rotation every nine hours and 20 minutes.

This design has formed the basis of many other rotating homes, such as the Everingham Rotating House in Australia, which was built in 2006 and works on much the same principle. It uses a 200-ton central bearing, 32 outrigger wheels to provide support, while movement is powered by two 500-watt electric motors. The Everingham house can complete a full circle in just half an hour, as well as using computer settings to place one of the wedge-shaped rooms facing toward the Sun.

However, if you're looking for a truly eco-friendly rotating building, you can't ignore the Heliotrop in Freiburg, Germany. Powered by a 120-watt electric motor, it only consumes 20 kilowatt-hours per year due to the structure following the Sun to make maximum use of the dual-axis solar panels on its roof. The central column is made of Kerto Q boards from Finland, strengthened by epoxy resin-filled steel ties.

As with all cool structures, there always has to be someone who goes bigger and better and in this particular instance, that person is David Fisher of Dynamic Architecture.

Fisher has drawn out plans for an immense 80-storey building, of which each floor rotates independently. Its revolutionary design also has each floor built in a factory before being attached in complete form to the central tower on site. With developments like these, buildings that continually adapt to their environment could well be the future of architecture.

House on the move

What tech does a building need to do a full 360? Here we focus on the Rotating Home near San Diego, California

AMAZING VIDEO!

SCAN THE QR CODE FOR A QUICK LINK

See what the Dynamic Skyscraper may look like

www.howitworksdaily.com

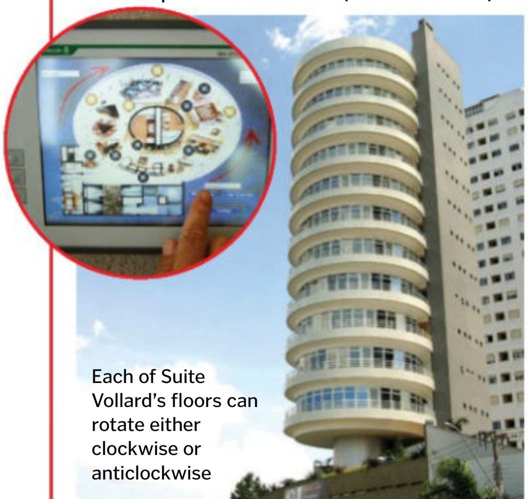
DID YOU KNOW? *The Sun rotates around the Earth at 15 degrees per hour, so that's the ideal house rotating speed for sunseekers*

Suites apart

The Suite Vollard became the world's first entirely rotating building, with work on architect Bruno de Franco's building finishing in 2001.

Built in the Ecoville District of Curitiba in Brazil, the 15-storey building has 11 floors of residential apartments that enjoy a single revolution every hour. As with the plans for the Dynamic Skyscraper, all the apartments are built around a static central column made of concrete.

Amazingly a single rotation of the building needs only the same energy as a standard hairdryer. Each apartment is on a separate floor, which means that inhabitants are able to control the speed of their own rotation independently via a control panel in their home (see inset below).



Each of Suite Vollard's floors can rotate either clockwise or anticlockwise

Pioneering spinner

One of the most famous early examples of a building in rotation is the BT Tower in London. This 190-metre (623-foot)-tall TV tower is topped by a restaurant that rotated from its opening in 1966 until it closed in 1980 over security fears.

At the time, the tower was an engineering marvel, completing a full rotation every 22 and a half minutes, offering diners a panoramic view of the London skyline. The construction only required a two-horsepower electric motor to power the 0.27-kilometre (0.17-mile)-per-hour rotation. Allowing the top of the tower to move was a series of nylon bearings and rollers.

Despite being stationary today, the BT Tower remains one of London's most iconic landmarks and it has provided inspiration for many of the fully rotating buildings emerging today.

The Heliotrop in Freiburg, Germany, actually uses rotation to save energy, via solar panels on the roof

Left: The Space Needle in Seattle, USA, has an observation deck and a rotating restaurant at the top

Life on board the Mary Rose

Explore Henry VIII's incredible flagship deck by deck

One of the most famous ships of the age, the Mary Rose is perhaps best known for its tragic demise on 19 July 1545 as it raced out of Portsmouth Harbour to meet the invading French fleet. The vessel, however, has a much longer history than this.

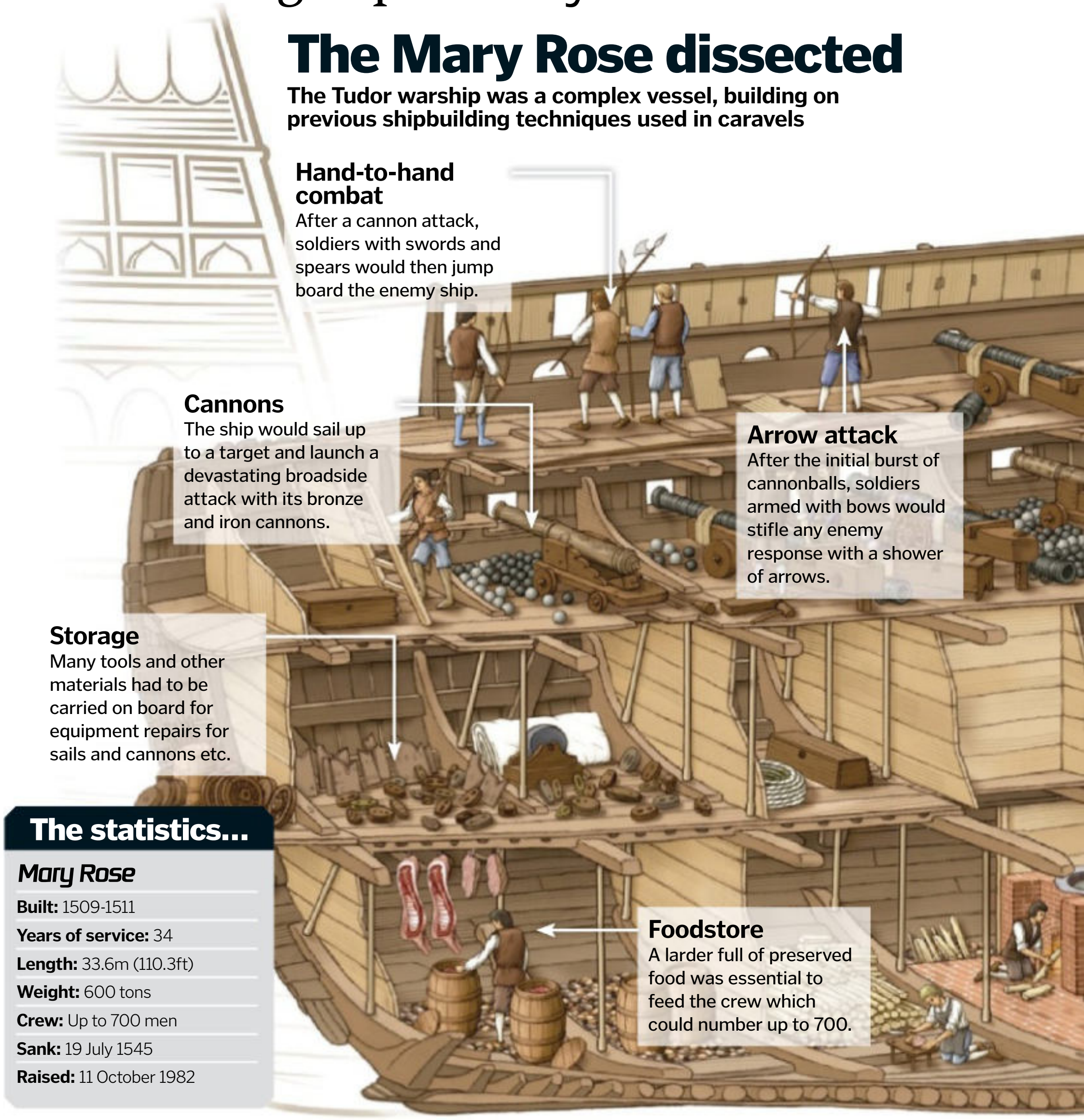
Launched in 1511, the ship engaged in 34 years of service until its sinking at the Battle of the Solent. Built to be part of the Royal Navy that protected England's seas, the ship was a carrack, or great ship, with four masts and was a technological advancement in its own right. Upon engagement in battle, the Mary Rose would fire broadside shots from its many cannons before the crew would look to board the enemy ship.

The Mary Rose was overhauled in 1527 after years of being kept in reserve. The planking was changed to allow space for larger guns with watertight lids. It could now fire shots farther to even hit shoreline targets.

Various theories have tried to explain why it sank. Many claim the crew misjudged the speed and turning circle in the harbour, which unbalanced the vessel and caused it to roll on its side and allow water to rush in. Another describes a gust of wind striking at a vital moment, causing it to capsize. For what came to be its final battle, the ship had been packed with soldiers and guns to engage the enemy. Some think the sheer weight proved too much of a strain. Lastly, an eyewitness account from a French officer claimed that a French cannonball was the culprit, but as yet there is no archaeological evidence to prove that.

The Mary Rose dissected

The Tudor warship was a complex vessel, building on previous shipbuilding techniques used in caravels



The statistics...

Mary Rose

Built: 1509-1511
Years of service: 34
Length: 33.6m (110.3ft)
Weight: 600 tons
Crew: Up to 700 men
Sank: 19 July 1545
Raised: 11 October 1982

A great ship's life

The Mary Rose's eventful history from its construction to its surprise sinking

1509
Construction starts on the ship. It is finally completed and launched in 1511.

1512
The Mary Rose engages in combat for the first time in the First French War.

1513-1522
Chosen as the flagship of the English fleet, it is used in various missions against the Scots and the French, ranging from soldier transportation to sea warfare.

1522-1535
The ship is kept in reserve and given a refit. The wooden planking is improved and more bronze and iron guns are added.

5 TOP FACTS
MARY ROSE TRIVIA

Rose by any other name
1 The ship could possibly be named after the Tudors' Rose crest, the Virgin Mary or Henry VIII's sister, Mary Tudor, who would later go on to become the queen of France.

To battle!
2 The Mary Rose first engaged in battle in 1512. It functioned as both a flagship and a transport vessel in numerous skirmishes against the French and the Scots.

A big crew
3 There could be as many as 700 men on board with roles including gunners, sailors and soldiers. Around 90 per cent of the crew perished in the seas of the Solent.

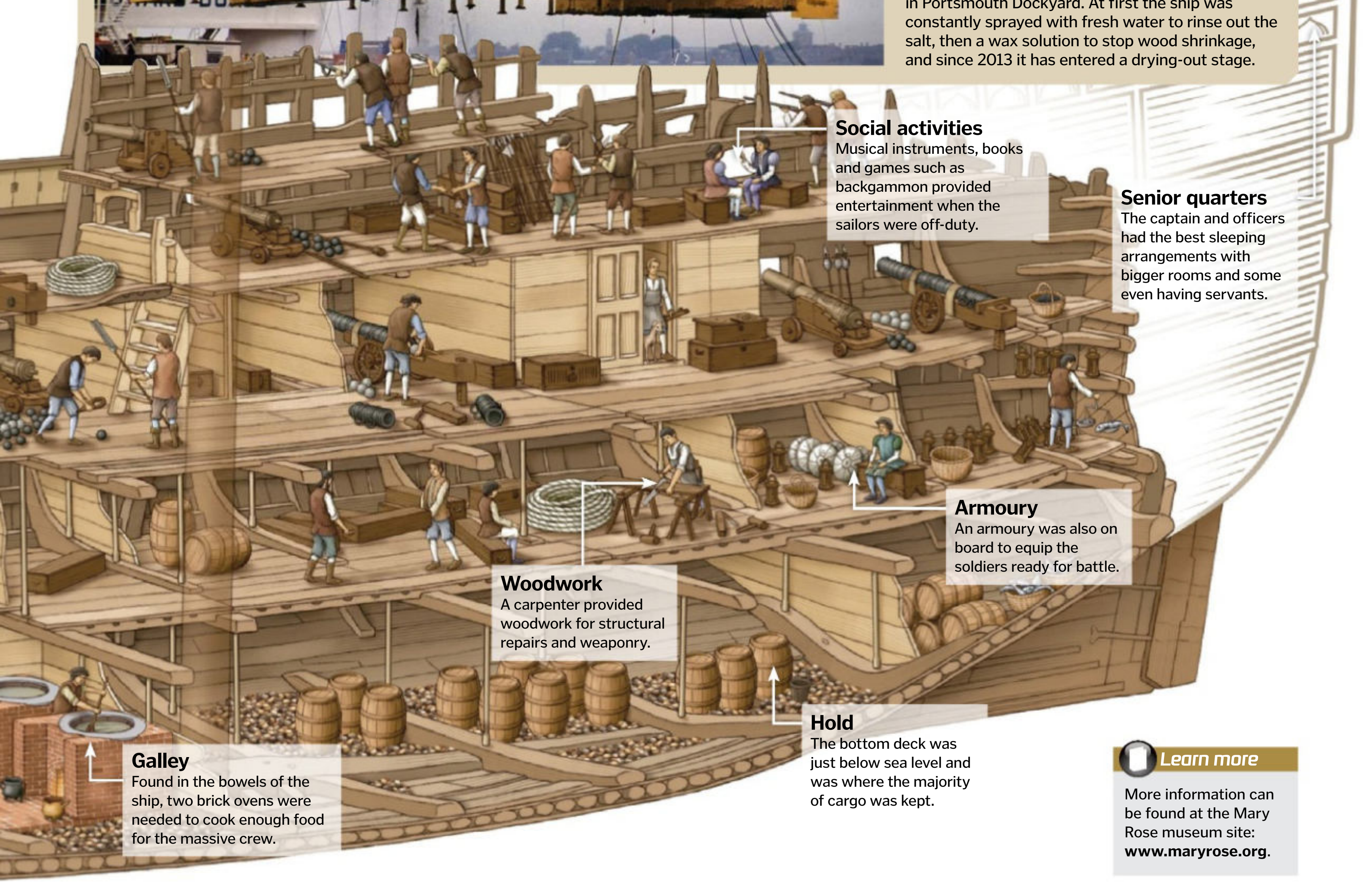
Haul of artefacts
4 Items found in the wreckage included food, musical instruments and surgeons' tools as well as conventional finds like weapons and navigating equipment.

A tricky operation
5 The total time spent on recovery missions to salvage the Mary Rose adds up to 22,710 hours of salvaging. That's the equivalent of more than 946 days!

DID YOU KNOW? *27,831 dives were made to the Mary Rose during the modern excavation project*

How the Mary Rose wreck was raised

Over the centuries since its sinking, there have been numerous attempts to raise the ship from the seabed. Salvage missions were ordered days after the sinking but the technology at the time was not advanced enough. It was left to deteriorate until rediscovered in the 19th century. Divers went down and many artefacts were retrieved but still no ship emerged. The Mary Rose finally saw the light of day in 1982, using a lifting frame and floating crane to hold it together as it was transported to dry land. The wreck is now housed in the Mary Rose Museum in Portsmouth Dockyard. At first the ship was constantly sprayed with fresh water to rinse out the salt, then a wax solution to stop wood shrinkage, and since 2013 it has entered a drying-out stage.



Learn more

More information can be found at the Mary Rose museum site: **www.maryrose.org**.

1545
The ship's fate is sealed as it sinks in Portsmouth Harbour after attempting to engage in combat. There are efforts to retrieve it from the seabed but all fail.

1836
After more than 290 undisturbed years, Charles and John Deane rediscover the Mary Rose after it catches on a local fisherman's net. More items are retrieved, including longbows and cannons.

1979
After the Deanes, the ship is again forgotten, until the Mary Rose Trust is set up and begins salvaging operations.

1982
The ship is finally raised on 11 October and work begins to house it in a special building where it can be preserved.

1. FAST
AH-64 Apache
This rugged military helicopter is able to reach 284km/h (176mph) despite being laden with defence armour and a range of weapons.

2. FASTER
Sikorsky X2
Became the first helicopter to reach 463km/h (288mph) per hour in 2010 at the Sikorsky Development Flight Center.

3. FASTEST
Eurocopter X3
This superfast flying machine broke the helicopter air speed record by travelling at a blistering 472km/h (293mph) in June 2013.

DID YOU KNOW? Pocket watches were originally worn around the neck, before they became small enough for the pocket

The origins of helicopters

How did we first take to the skies on an aircraft without wings?

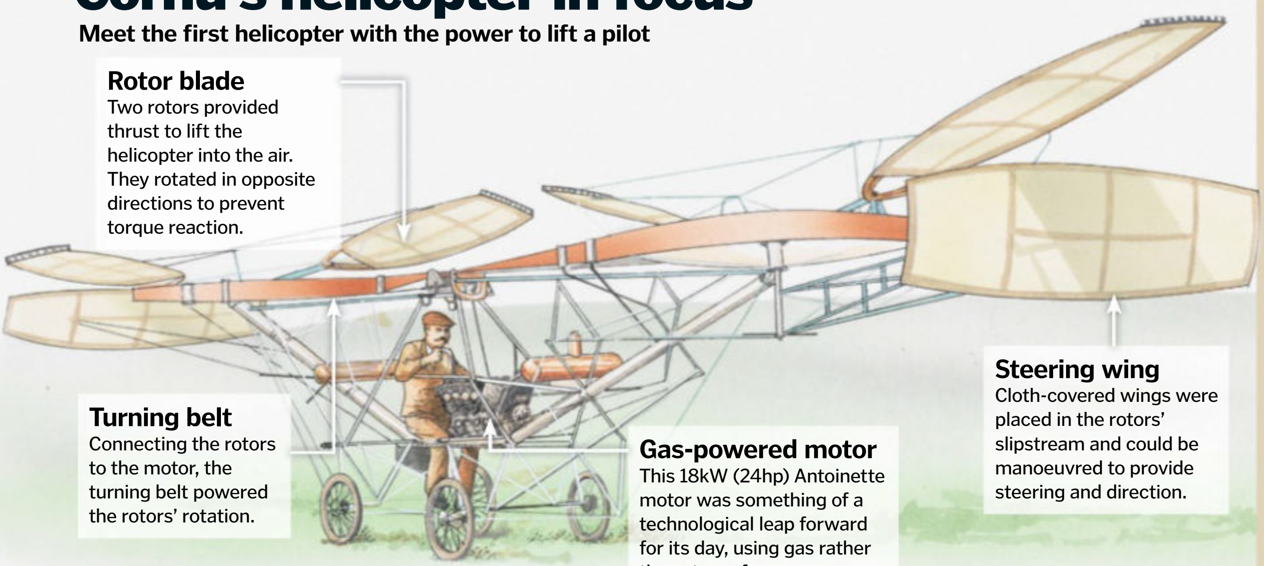
Leonardo da Vinci is the first recorded person to consider the helicopter as a means of transport. He designed an air gyroscope in 1483 with rotating blades and an iron screw to cut through the air.

The late-19th century saw the next big leap forward in helicopter flight, with Englishman Horatio Phillips using a steam engine to power a vertical flying machine. However, Frenchman Paul Cornu used a simple frame, a pair of rotors connected by a belt to a gas-powered motor to lift a person off the ground for the first time.

The Fa-61, built by Heinrich Focke in 1936, was the first to demonstrate controlled flight using a rudder, while Igor Sikorsky pushed this development even further in 1940 with a rotor on the tail to improve steering. Finally, in the 1940s, Sikorsky's R-4 helicopter, now with the ability to move forward at speed and with greater control, became the world's first commercially viable helicopter.

Cornu's helicopter in focus

Meet the first helicopter with the power to lift a pilot



Rotor blade
Two rotors provided thrust to lift the helicopter into the air. They rotated in opposite directions to prevent torque reaction.

Turning belt
Connecting the rotors to the motor, the turning belt powered the rotors' rotation.

Gas-powered motor
This 18kW (24hp) Antoinette motor was something of a technological leap forward for its day, using gas rather than steam for power.

Steering wing
Cloth-covered wings were placed in the rotors' slipstream and could be manoeuvred to provide steering and direction.

Helicopter flight physics

A helicopter is an enigma of flight as it doesn't look like it should work. But with careful piloting, they can go places no plane can.

The helicopter motor rotates the blades at high speed. By pressing the collective-pitch lever, the pilot raises the rotor blades to a particular angle. The blades generates lift as they are spun rapidly, with the tail rotor providing sideways force to stop the helicopter spinning out of control as it leaves the ground.

In order to move forward, the rotor blades are angled down at the front. This results in more lift at the back, propelling the chopper forward. Meanwhile, foot pedals are used to control the tail rotor speed, which will direct a helicopter to the left or right.

Pocket watches explained

Find out what's going on inside these portable timekeepers…

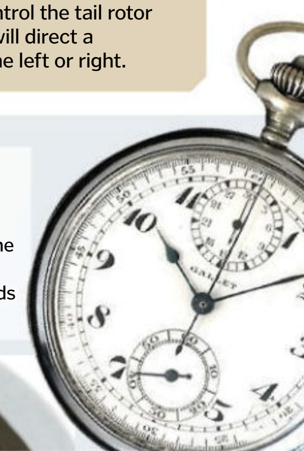
German watchmaker Peter Henlein is considered the father of pocket watches. His spring-based design involves winding up a watch and compressing a coiled spring. The coil's steady expansion provides the energy for the gears to turn, pushing the hand around via a wheel. The first pocket watches only had an hour hand but, as time went by, minute and second hands were added, operated by interlocking gears.

Initially, pocket watches had to be wound twice a day, as the hour hand completed two full rotations, but as more hands were added, watches only needed winding once a day.

Henlein's design was so successful that the mainspring design is still being used today, despite being over 500 years old.

Inside a pocket watch

What makes these mini timepieces tick?



Centre wheel
This is the piece upon which all the other gears rest. The front pivot of the centre wheel drives the cogs which turn the hands on the face.

Hour and minute wheels
These interlock and are moved by the steady expansion of the mainspring pushing against the centre wheel.

Gem bearings
Precious stones such as rubies were used inside watches as bearings, helping mechanical parts move more smoothly, reducing wear and tear.

Mainspring
Below the wheels the mainspring is wound by an external winder, expanding steadily to push all moving parts.

Balance wheel
The timekeeping part of the watch. It oscillates back and forth at a regular speed to ensure the hands don't move too fast or slow.

Casing
The earliest pocket watches were housed in a steel casing, which was strong and cheap. Later, more refined versions used brass, gold and silver.

“Despite the dire conditions, the sheer number of jobs available saw the working class flock to cotton mills”

Inside a cotton mill

Understand the workings of one of the cornerstones of the Industrial Revolution and how cotton changed the world

In the 19th century, cotton production was one of the most profitable enterprises around. Western society had long been split into a two-tier system, with the aristocracy controlling over 90 per cent of the nation's wealth, with the rest left virtually penniless. The Industrial Revolution changed that, with a new merchant middle-class becoming a significant financial power.

With the middle class's ascension came an increased need for quality fabric products. But while the need for cotton had grown, the cotton industry itself was still largely restricted to a series of cottage industries – small home-grown businesses staffed by manual labourers who were unable to keep pace with demand. Luckily, automated machines such as the self-actuating spinning mule and power loom were invented that enabled cotton to be processed, spun and woven at a scale that not only could meet demand but also rendered these cottage industries obsolete.

And so was born the cotton mill. These were staffed with the remnants of the former cottage industries as well as hundreds and thousands of others, with workers no longer required to hold proficiency in traditional skills such as sewing but instead simply be capable of operating the machines that now did everything for them.

Conditions were poor for the workers, with people of all ages – including children – exposed to potentially crippling machines as well as hot and dusty conditions that often led to fatal ailments. Workers frequently lost fingers and even limbs while operating the machinery too.

Despite the dire conditions, the sheer number of jobs available – to women and men alike, granting the former an independent income – saw the working class flock to cotton mills, with people often travelling across the country to cotton hotspots like Lancashire to earn some money. Many mill owners also offered packages that, before that point, the working class simply would never have dreamed of, often including free accommodation and even a rudimentary education for their children as an incentive to work there.

As the Industrial Revolution came to a close, the industry went into decline. By the early-20th century, cotton yarn and fabrics were now being produced all over the world, with new industrial heartlands emerging in Asia. This meant that by 1950 the age of the cotton mill was over, with its once bustling rooms falling silent.

A stitch in time...

Follow the key developments in the history of cotton with this quick timeline

5000 BCE
Treated cotton bolls and pieces of cotton cloth in Mexican caves date to around 7,000 years ago.

3000 BCE
The Harappan civilisation in what is Pakistan today grows, spins and weaves cotton during the Bronze Age.

800 CE
Arab merchants begin importing Eastern-made cotton into Europe in large quantities for the first time.

1500
Cotton is now used throughout the world. Its production remains restricted to cottage industries though.

HEAD 2 HEAD
FATAL FACTORIES

1. DEADLY

Textile factory
With powerful machines designed to shred and tear, a tiny lapse in concentration could mean losing a limb, potentially dying from blood loss or infection.

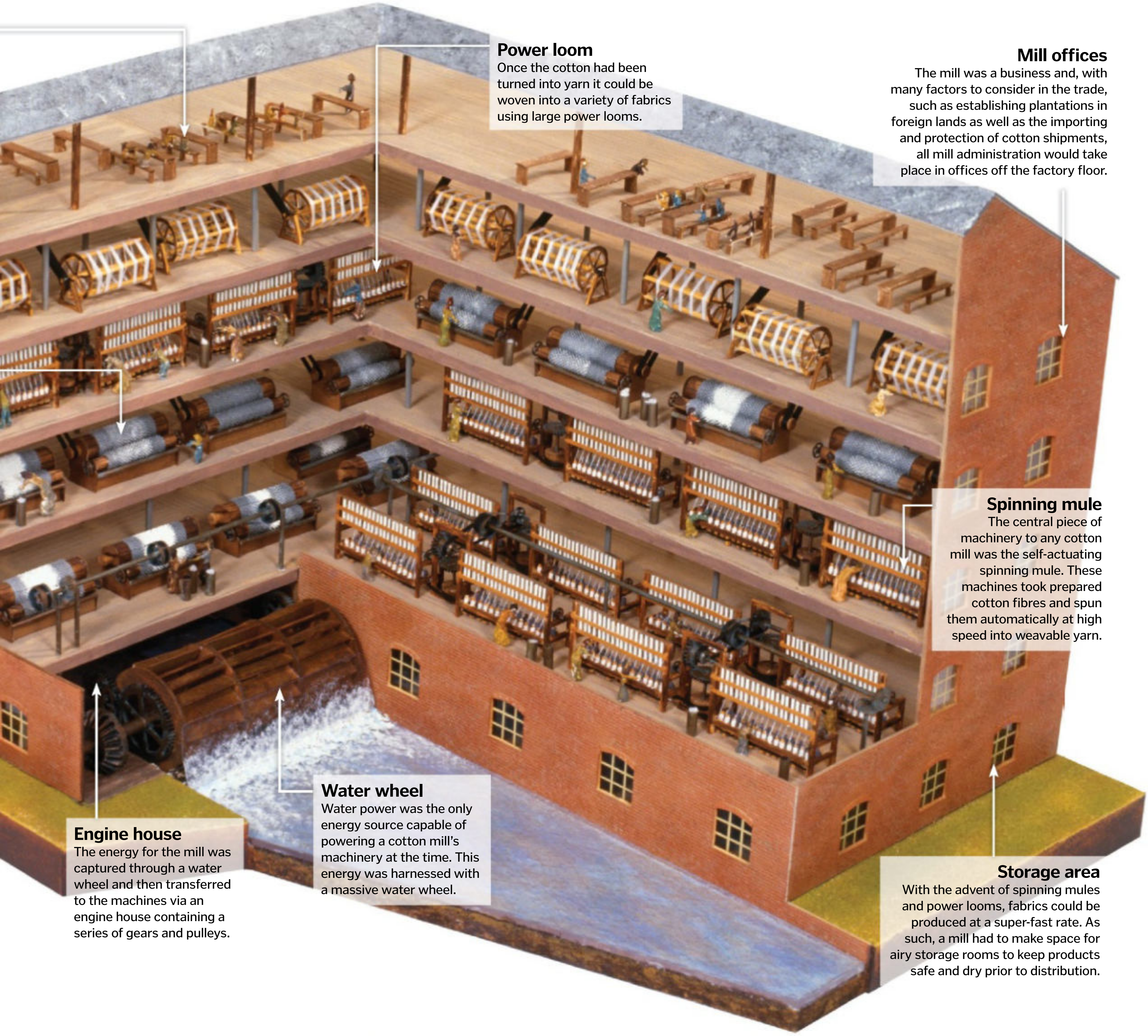
2. DEADLIER

Coal plant
Extracting coal from mines was bad enough, but workers who processed it in poorly ventilated factories often died young from lung diseases too.

3. DEADLIEST

Metallurgy forge
The production of metals in super-hot and insanely hazardous furnaces inevitably led to many horrific burns and deaths.

DID YOU KNOW? *In 1833, England's largest cotton mill employed over 1,500 people*



1730
The first machines to automatically process and spin cotton are put into use.

1741
The world's first mill designed to spin cotton mechanically is opened by English engineers Lewis Paul and John Wyatt.

1794
US inventor Eli Whitney patents the 'cotton gin', a machine that can separate cotton fibres from their seeds.

1824
English inventor Richard Roberts creates his most famous machine, the spinning mule, which can spin cotton at a rate unimaginable to manual spinners.

1855
In the mid-19th century cotton production enters a golden age, with huge mills being built.

1950
100 years on many mills have closed and those that survive become increasingly automatic, with electric engines.

BRAIN DUMP

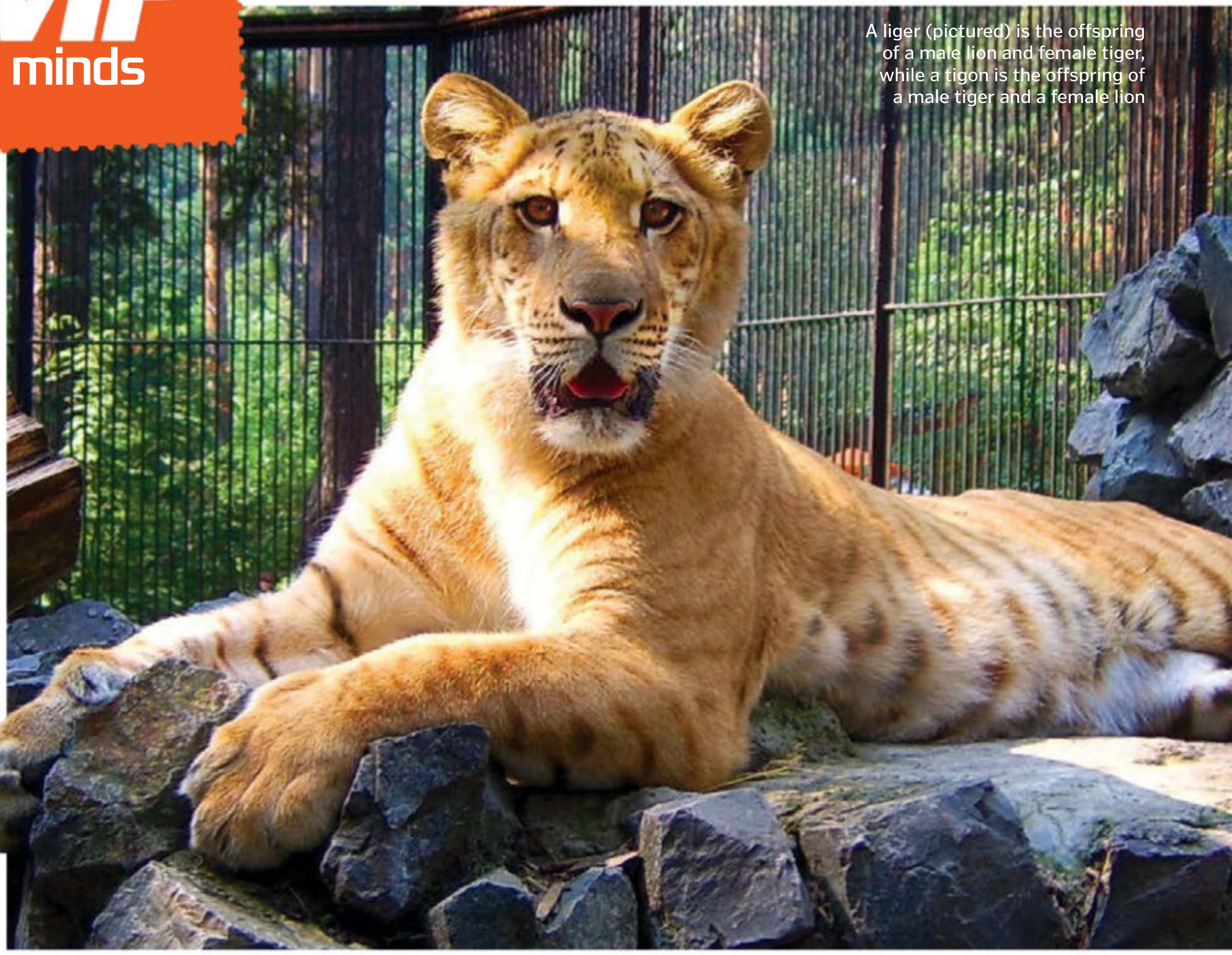
Because enquiring minds need to know...

Want answers?

Send your questions to...

How It Works magazine @HowItWorksmag

howitworks@imagine-publishing.co.uk



A liger (pictured) is the offspring of a male lion and female tiger, while a tigon is the offspring of a male tiger and a female lion

MEET THE EXPERTS

Who's answering your questions this month?

Luis Villazon

Luis has a degree in zoology and another in real-time computing. He's been writing about science and technology since before the web. His science-fiction novel, *A Jar Of Wasps*, is published by Anarchy Books.

Dave Roos

A freelance writer based in the United States, Dave has written about every conceivable topic, from the history of baseball to the expansion of the universe. He has an insatiable appetite for science and technology.

Alexandra Cheung

Having earned degrees from the University of Nottingham as well as Imperial College, Alex has worked at many a prestigious institution around the world, including CERN, London's Science Museum and the Institute of Physics.

Rik Sargent

Rik is a science communicator who has a background in physics and public engagement, having worked at the Institute of Physics. Pastimes include experimenting with sound, baking cakes as well as the complex science of brewing coffee.

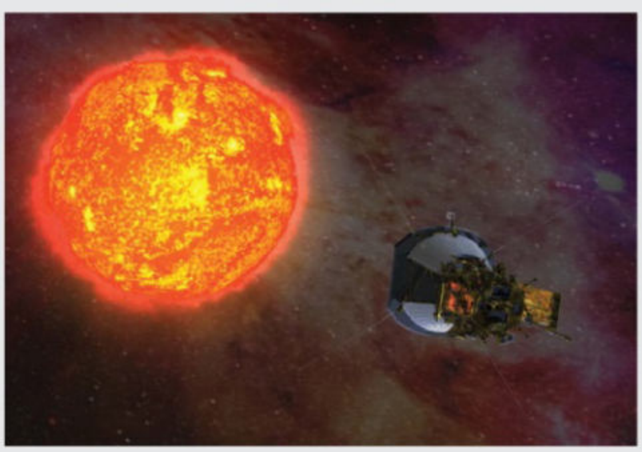
Shanna Freeman

Shanna describes herself as somebody who knows a little bit about a lot of different things. That's what comes of writing about everything from space travel to how cheese is made. She finds her job comes in very handy for quizzes!

Do cross-breed cats like tigons and ligers appear in the wild?

Shelley Wasser

■ It's very unlikely. Tigers and lions don't share the same habitat anywhere in the wild, so they don't have the opportunity to interbreed any more. The only place it could have happened is India but the Asiatic lion is now confined to one small population in the state of Gujarat and tigers have been extinct there since at least 2001. Even if they were to meet, tigers and lions have very different social structures and mating behaviours. Hybrid mating does occasionally occur in the wild, but the offspring are less fertile than the parents, so natural selection favours animals that stick to their own species. **LV**



Does the Sun smell of anything?

Jessica (7)

It's difficult to know because we haven't gotten very close to it – that should change in 2018 when NASA launches its Solar Probe Plus mission, designed to actually enter the Sun's atmosphere. We do know what space smells like, thanks to spacewalks by astronauts. Of course they can't smell it through their suits, but when they come back inside, their suits and instruments have a distinctive odour. Some astronauts have described it as smelling like a grilled steak, heated metal, or in the words of astronaut Don Pettit, "pleasant, sweet-smelling welding fumes." A chemist has even re-created the smell on Earth for astronauts in training. **SF**

How was the Millennium Eye built?

Daniel Jessop

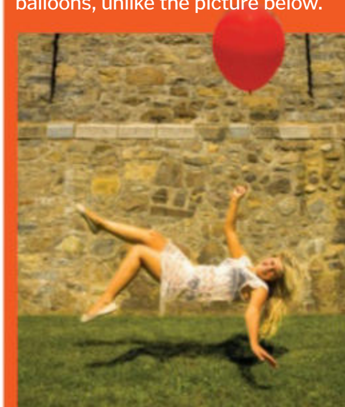
■ The Millennium Eye, or London Eye, is unique among observation Ferris wheels. All of the wheel's main components were built separately off-site and came from six different countries. They were then floated on barges up the River Thames to the Eye's South Bank location, which presented some challenges – once loaded onto trailers each capsule measured 4.9 metres (16 feet) tall, requiring careful route planning on their journey to avoid low bridges. The Eye was assembled horizontally on platforms in the river next to the site, with a massive floating crane lifting the rim sections into place. Once the wheel was assembled, the Eye was raised upright using hydraulic strand jacks. There was a hiccup as a temporary cable snapped, but over the course of a week the Eye was raised in stages and secured, before the capsules were attached to the rim. **SF**

Standing 135m (443ft) tall the London Eye has become an iconic landmark of the city

COOL FACTS

It takes thousands of balloons to lift a human

It takes one litre of helium to lift a gram (0.04 ounces). To lift a 70-kilogram (154-pound) person, you would therefore need 70,000 litres of helium, or roughly 5,000 balloons, unlike the picture below.



Where in the world did snooker originate?

Neil Tate

■ Snooker's origins date to 1875 in a British officer's mess in Jabalpur, India. By the late-19th century, Europeans had been playing variations of billiards for nearly three centuries. Billiards was a betting game and the most popular types were 'pool' games in which players pooled their bets. During a monsoon season, Sir Neville Chamberlain (a colonel, not the British prime minister) proposed a combination of three existing pool games that used a rack of 15 red balls plus six coloured balls and a white cue ball. The name snooker derived from a slang term for first-year cadets. **DR**

How does LiFi internet work?

Mahaya Sangakkara

■ LiFi is just like WiFi, except that instead of sending network data using radio waves, it uses light. Visible light and radio waves are both electromagnetic waves but the visible part of the spectrum is about 10,000 times wider than the radio frequencies allocated to WiFi. Current LiFi systems are still experimental but they could eventually be incorporated into phones and other gadgets using a single LED bulb that flickers on and off too fast for the eye to detect. Although LiFi won't travel through walls, it doesn't need direct line of sight because it can also work by reflecting off surfaces. **LV**

Why is Alaska part of the USA but not connected to it?

Ian Molinder

■ Alaska became part of the United States in 1867 after it was purchased from Russia for $7.2 million, roughly £71.6 million ($119 million) in today's currency. Russian fur traders began settling the Alaskan coast in the early-18th century, decimating the native Aleut tribes with Western diseases. After losing the Crimean War in 1856, Russia abandoned plans to develop Alaska as a strategic military post. Rather than let Alaska fall into British hands, Russia offered to sell the land to the US. Alaska was first a 'territory' and a 'district' before becoming the 49th US state in 1959. **DR**

Why do clouds come in all shapes and sizes? Find out on page 82

Why are there so many cloud types?

Danielle Yeoman

The air temperature drops as you get higher and convection currents create distinct layers within the atmosphere, so the appearance of a cloud depends on where it forms. The highest-altitude clouds are composed of tiny ice crystals. These clouds are diffuse enough to be partly transparent and so light that they are easily blown into wispy shapes by air turbulence. Between 2,000 and 6,000 metres (6,560 and 19,685 feet), clouds are mainly composed of water droplets, which absorb more light so they appear more opaque, and the attraction between droplets tends to keep clouds grouped together into rounder shapes. Advancing weather fronts can create bands of cloud like waves rolling onto a beach. Below 2,000 metres (6,560 feet), the droplets clump together into larger drops that absorb enough light to appear dark grey and the clouds are affected by convection currents rising off the ground, flattening the underside. **LV**

COOL FACTS

Radon is a gassy heavyweight

Which gas is heaviest depends on a number of factors. Radon is one of the densest gases at standard room temperature and pressure – about eight times the density of the Earth's atmosphere.

More of us are scared of spiders than anything else

The world's most common phobia is arachnophobia, affecting up to six per cent of the population. The reasons for this being such a common phobia remain uncertain.

Holland isn't the flattest country

The Maldives, a cluster of 26 atolls in the Indian Ocean, is actually the world's flattest country with an average elevation of 1.5 metres (4.9 feet) and a natural high point of just 2.4 metres (7.9 feet).

What is the most dangerous household appliance?

Dean (10)

Cooking appliances are a major cause of accidental fires, causing more serious injuries and deaths than any other household devices. In the UK, they resulted in 33 fatalities and 4,100 injuries in 2011 and 2012. Roughly half were caused by stoves, while chip pans were the second-most likely item to spark a fire in the kitchen. Space heaters are another common culprit, going up in flames when their ventilation is blocked or wet clothes drip onto them. Lint buildup in dryers and electrical malfunctions in microwaves, refrigerators, freezers and dishwashers also cause many injuries due to fires. **AC**

Who made the first spirit level?

Karl Jensson

Melchisédech Thévenot, a French author and scientist, invented the spirit level in 1661. Thévenot's spirit level was similar to those in use today, in that it used a bubble of air inside a container filled with alcohol to determine whether a surface was horizontal (level) or vertical (plumb). The container was mounted on a stone ruler and had a viewing lens.

Thévenot's invention did not come into widespread use until the beginning of the 1700s, however there is some evidence that spirit levels of this type were used long before the turn of the 18th century both in France and farther afield. **RS**

Alcohol disrupts the areas of the brain that co-ordinate our movements and process logic

Why does alcohol make us lose our inhibitions?

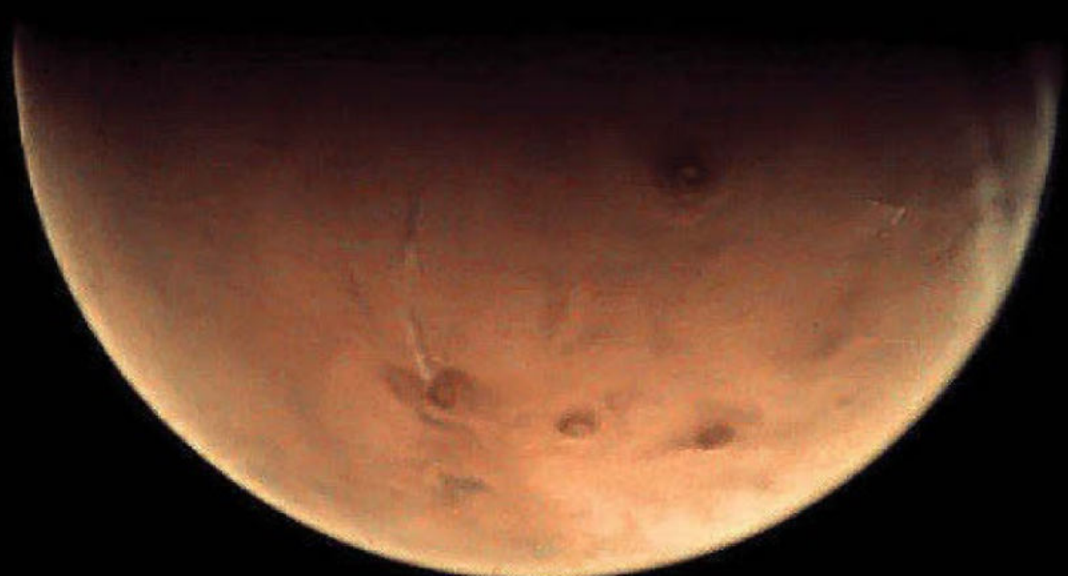
Garry Jones

When alcohol enters the bloodstream, it travels to different parts of the brain, each responsible for different motor skills, thought processes and emotional responses. The cerebral cortex is largely responsible for processing information and making sound decisions. When the functioning of the cerebral cortex is depressed, the result is decreased inhibition (greater than normal sociability, talkativeness and flirtatiousness) and impaired reasoning skills, a combination that can be observed on any given Saturday night at watering holes across the globe. **DR**

Pictures taken from space never seem to have stars behind the planets – why is that?

Isaac Elm

There are so many stars visible to the naked eye in our night sky that it seems reasonable for stars to be seen in all photos taken from space. However, images of planets are taken using daylight camera settings with short exposure, because the planets are lit by the Sun. The stars simply aren't bright enough to appear in images in which they aren't the intended subjects. For astronauts to see stars in space, there can't be anything lit by sunlight in their field of vision – and photographing stars means using longer exposure times than those used to shoot planets. **SF**



Did Spartans do anything other than fight? Find out on page 84

BRAIN DUMP

Were Spartans really obsessed with fighting?

Harrison McFarlane

Spartan culture was largely centred on the development of their military, but they were also a deeply religious and cultural people who enjoyed music, dance, poetry, art and sporting events. The city of Sparta housed prominent buildings, temples and a theatre. Spartan bronze products were of an extremely high quality and were viewed as valuable diplomatic gifts.

Spartan society gave women economical power and influence and girls received a public education and engaged in sports – all things unheard of in neighbouring Greek societies in 600 BCE.

Historians know of four Spartan poets whose works were praised by critics throughout the world and the Spartans were known to regularly hold popular music and dance festivals.

It is impossible not to recognise the exceptional nature of Spartan military achievements, which is largely why other aspects of Spartan culture get overlooked. However after two costly wars in the late-eighth and early-seventh century BCE, the Spartans increasingly sought diplomatic means to solve conflicts. **RS**

COOL FACTS

Madagascan mammals have the most babies

Litter size in mammals is related to the number of nipples and the winner there is the Madagascan tailless tenrec. Females can have 29 nipples and huge litters of up to 32.

The ride may only last 90 seconds but thrillseekers on the Formula Rossa will experience up to 1.7Gs

Where is the fastest rollercoaster?

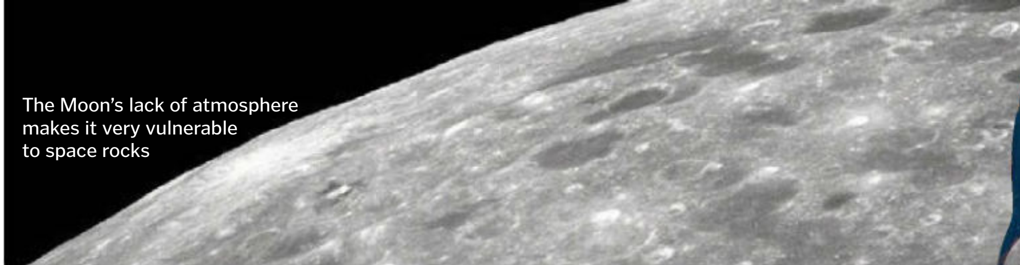
Zach Hounslow

Formula Rossa located at Ferrari World in Abu Dhabi, United Arab Emirates, is the speediest rollercoaster in the world. Reaching speeds up to 240 kilometres (150 miles) per hour in under five seconds, the ride uses a hydraulic launch system – the same technology used in aircraft carrier catapults – and generates 20,800 horsepower. Passengers are exposed to 1.7Gs as they are catapulted along 2.1 kilometres (1.3 miles) of track with sharp turns and sudden drops, in under 90 seconds. The track shape was inspired by the famous Italian racetrack in Monza. Because of the extreme wind speeds reached, all passengers must wear protective glasses. **RS**

Can a computer compose music?

Aimee Wu

Certainly. Music composition isn't an entirely free-form process; even when humans compose music, they follow certain rules that define which notes belong in a scale and which chords belong in a key. It is quite possible to use computer algorithms to take those rules and a lot of other more subtle ones to create quite passable music. *Band-in-a-Box* is a Windows and Mac program that can improvise an accompaniment to any tune, while the Iamus computer cluster (right) at the University of Málaga in Spain, can compose a full-length classical symphony in a mere eight minutes! **LV**



The Moon's lack of atmosphere makes it very vulnerable to space rocks

How often is the Moon hit by asteroids?

Oliver

■ We know asteroids hit the Moon all the time. In February, astronomers announced that a huge asteroid with a mass of about 400 kilograms (882 pounds) smashed into the Moon last autumn, producing a flash confirmed to be the brightest ever observed from a lunar impact. Another huge impact was recorded six months prior. Unlike on Earth, there's no atmosphere there to stop them. However, we aren't sure how often these impacts happen, because until recently, we haven't had many telescopes set up to observe them. Now there are several systems, including the Moon Impacts Detection and Analysis System (MIDAS) in Spain and NASA's Automated Lunar and Meteor Observatory (ALAMO) that can automatically detect lunar impacts. **SF**

Do men and women think differently?

Beth G

■ Male and female brains are structured differently, suggesting that there is some variation in the way their owners think. Certain regions of men's brains are larger than women's, and vice versa. Studies have also shown that women and men use different parts of their brains to solve the same problems. The wiring of our brains could also have an impact on how we think. In female brains, there are strong neural connections between the left and right hemispheres, linking areas associated with logical thinking. This could give women the upper hand when it comes to social skills, memory or multitasking. In men's brains, denser circuitry connects the front and back of the brain, linking areas focusing on perception and action, which may endow men with better motor skills. While these studies uncovered average trends, any one individual is likely to combine characteristics of the 'male' and 'female' brains. **AC**

King Arthur's legend grew massively after the Norman invasion, as Celtic regions sought to reaffirm their past through heroic tales

Did King Arthur exist or was he just a legend?

Paula Winger

■ There is no historical evidence that King Arthur existed. Historical records from the Dark Ages are almost nonexistent, so little is known about fifth and sixth-century Britain – the time King Arthur supposedly established the Knights of the Round Table, defeated the Saxons and built an empire. The first reference to a king called Arthur only crops up in the ninth century, written by a reclusive Welsh monk called Nennius. **RS**

How does dry cleaning work?

Tuneth Knott

■ Dry cleaning isn't actually 'dry' at all; it's a process that uses a liquid chemical solvent to remove dirt and stains from clothing that's easily damaged or shrunk. A normal washing machine soaks clothes in soapy water, agitates them, then rinses and spins them dry. Wool, silk and certain polyester fibres can shrink or lose colour in washing machines. In dry cleaning, clothes are sprayed with a liquid solvent and tossed gently in large, professional-grade machines that double as dryers. The majority of dry cleaners use a highly toxic, petroleum-based solvent called perchloroethylene, or 'perc', which cannot be touched or inhaled. 'Green' dry cleaners now use liquefied CO_2. The final step in dry cleaning is to press the clothes using industrial steam presses. **DR**

Why are Ming vases so expensive?

Richard Ecclestone

■ Ming vases' great age, their rarity and above all their enduring popularity with art collectors explain their exorbitant price tags. Ming vases were produced in China at the time of the Ming dynasty (1368-1644), using new technology that created porcelain of unprecedented quality. Trade routes carried Ming vases to Europe, fuelling a craze among nobles and royalty between the 16th and 18th centuries. Nowadays the vases are particularly sought after by China's increasing number of millionaires, continuing to drive up prices. The most expensive Ming vase was sold at an auction in 2011 for a massive £13 million ($21.6 million). **AC**

New Brain Dump is here!

■ Don't miss issue 12 of **Brain Dump**, the digital sister magazine to **How It Works**, when it lands on the virtual newsstand on 1 May. You'll learn all about how NASA's thrusters work, if there's a way to cure baldness and if it's possible for an archer to split an arrow with another arrow. There are loads more trivia snippets for you to get stuck into, giving you the knowledge hit you need without having to lug an encyclopaedia around! Download the new issue of **Brain Dump** on the first day of every month from iTunes or Google Play. If you have a burning question, you can ask at **www.facebook.com/BraindumpMag** or Twitter – the handle is @BrainDumpMag.

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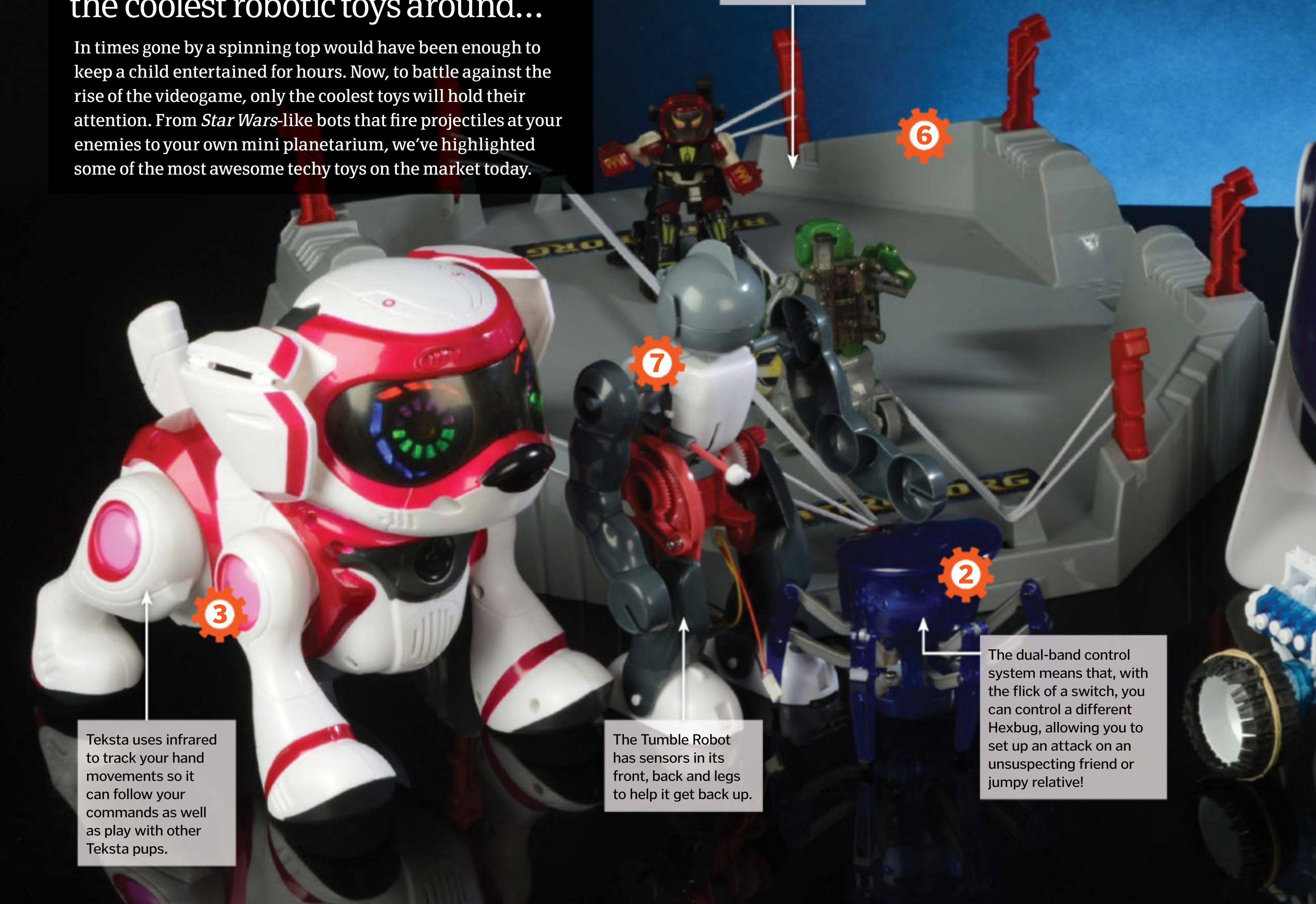
Techy toys

Stock up on batteries as we reveal the coolest robotic toys around…

In times gone by a spinning top would have been enough to keep a child entertained for hours. Now, to battle against the rise of the videogame, only the coolest toys will hold their attention. From *Star Wars*-like bots that fire projectiles at your enemies to your own mini planetarium, we've highlighted some of the most awesome techy toys on the market today.



1 Legging it

Attacknid
£49.99/$79.99
www.toysrus.com

Attacknids are awesome-looking remote-controlled robots that fire out foam discs at their owner's command while scampering around on six legs. Although we had trouble getting the remote control and robot to sync at first, when we did it worked superbly, firing its discs a fair distance, if in rather sporadic directions. This is great fun to play with – especially when you've got two Attacknid bots battling it out.

Verdict:

2 Creepy crawler

Hexbug Spider
£19.98/$24.99
www.hexbug.com

Attacknid's diminutive cousin, this palm-sized mechanical spider is a fun remote-controlled robot. Although it doesn't do a whole lot other than scurry about the room, startling your mates, if you make an assault course for it and race them, it's more of an event. The other good thing about it is that it's operational straight out of the box. There's also an app called *Hexbug Havoc* available (see 'Extras' box).

Verdict:

3 Robo-dog

Teksta Puppy
£51.95/$N/A
www.toysrus.co.uk

This adorable robot puppy is an updated version of a much earlier Teksta toy. While the variety of noises can get a little irritating after a while, kids will get a few hours' entertainment training Teksta to sit and do a flip. The response to hand movement is a tad hit and miss, but with a bit of time and effort, the Teksta Puppy does make for a good trial run before introducing a real four-legged friend to your home!

Verdict:

4 Indoor night sky

Deep Space Planetarium & Projector
£30/$85
www.amazon.com

With a simple flick of a switch, you can have the night sky in your bedroom. This planetarium can either project an image of the stars onto your ceiling or, if you flip it over and slot in one of the three slides, featuring incredible space phenomena, images of the Moon landing or the planets of our Solar System. The slide images are really sharp, even if the night sky isn't quite as clear as the others.

Verdict:

Checklist

- ✔ Attacknid
- ✔ Hexbug spider
- ✔ Saltwater car
- ✔ Robot puppy
- ✔ Boxing bots
- ✔ Space projector
- ✔ DIY robot

5 Salt-powered car

Salt Water Fuel Cell Engine
£14.95/$31.99
red5.co.uk / amazon.com

Despite starting life as an intimidating collection of tiny parts when you open the box, the Salt Water Fuel Cell Engine is surprisingly easy to assemble, as it comes with thorough and simple instructions. It will take you a few hours, but looks awesome when fully built and the fact it runs on just five drops of saltwater is nothing short of amazing. Only the best toys can be fun and educational!

Verdict:

6 Battling bots

Battroborg Battle Arena
£69.99/$79.99
tomy.com

Using Nintendo Wii-style Nunchuks, two Battroborgs line up to beat the merry hell out of one another until one of them falls over. Quick to set up and very straightforward to operate, these battling robots are brilliant fun to play with. They can be a little inaccurate in their attack manoeuvres, but with a little practice, a royal rumble of Battroborgs is a superb way to while away a rainy afternoon.

Verdict:

7 The new Weeble

Tumble Robot
£16.99/$19.99
www.toysrus.com

Now we don't like to encourage or advocate violence but this robot simply lives to be knocked down. After building the Tumble Robot, switch him on and he'll do a little dance for you. If he falls, or gets pushed, the Tumble Robot can get back up again every time. Easy to put together and interesting to watch, this toy from Edu Science has a limited range of functions but is still intriguing.

Verdict:

EXTRAS

When the batteries have run out, here are some alternative entertainment methods

BOOK

Toys! Amazing Stories Behind Some Great Inventions

Price: £10.87/$17.99
Get it from: amazon.co.uk / macmillan.com

A charming look back at some of the most iconic toys of all time and their origins. Learn the secrets of Lego, the Slinky, Mr Potato Head, Play-Doh and many more classics. A lovely book for the coffee table and a great nostalgia trip.

APP

Hexbug Havoc

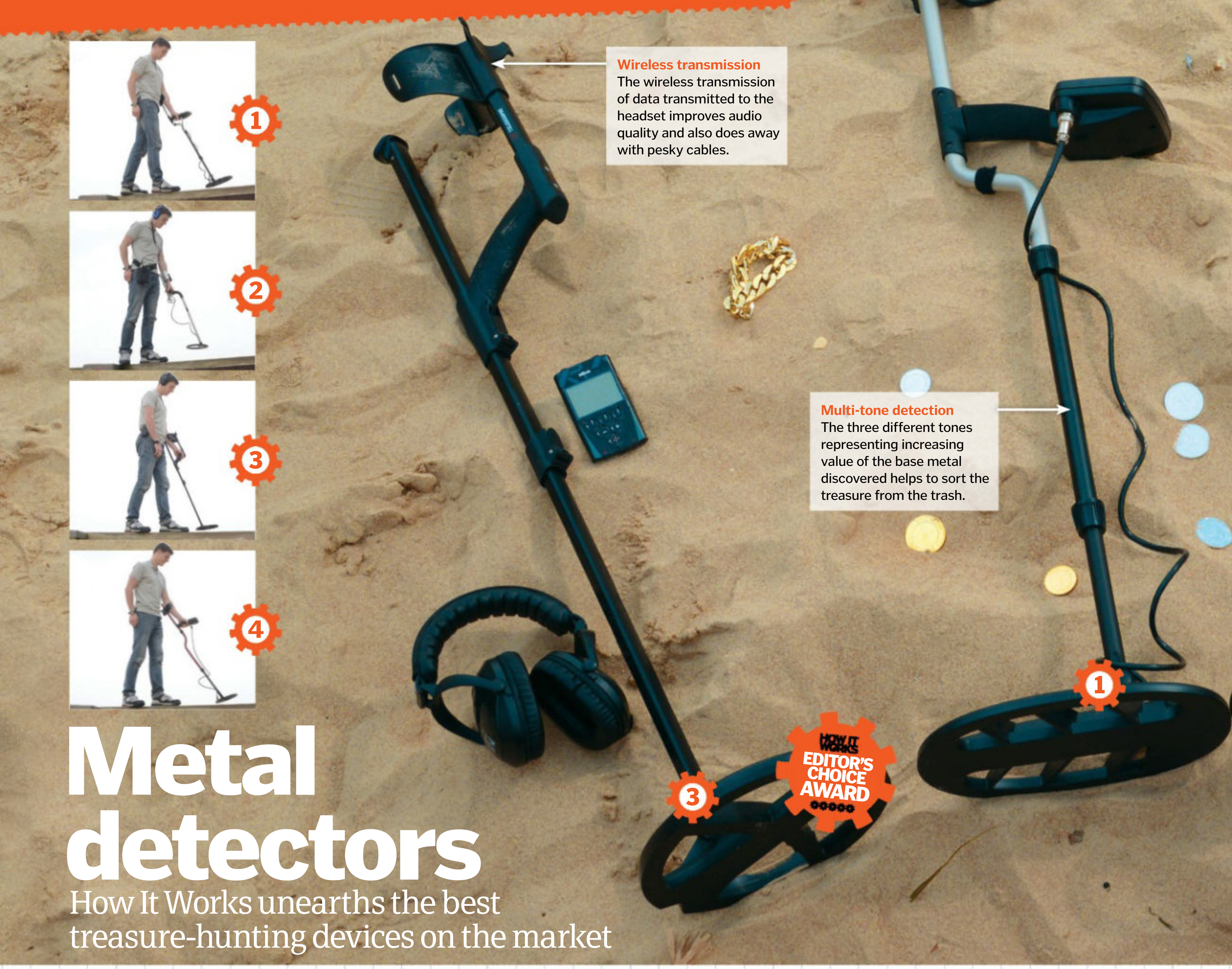
Price: Free
Get it from: iTunes

If you can't get the toy, download the app! Hexbug has come to your iPhone in an endless running game. Race through tunnels collecting coins as you go as well as battering enemy Hexbugs out of the way.

WEBSITE

news.toyark.com

The place to go for all the latest toy news and chatter. The Toyark is a vast community that breaks news about a huge range of toys as well as giving fans a platform to discuss their favourites.



Metal detectors

How It Works unearths the best treasure-hunting devices on the market

1 Teknetics Omega 8000

Price: £475/$599
Get it from: metaldetectorshop.co.uk / tekneticst2.com
One of the main problems with metal detecting is the sheer volume of trash that gets mistaken for treasure. The Omega 8000 is designed to eliminate that frustration as much as possible. One way it does that is by using different tones to indicate the different types of metal that it has found. Iron gets a low tone, while coins register a higher tone, meaning that you can differentiate between a rusty nail and a Roman coin without having to waste time digging.

The Omega 8000 also adjusts depending on the terrain you are searching on, allowing for varying levels of natural minerals in the soil. It is extremely easy to set up, taking only five minutes to assemble and the quick start, in which you teach it the discrimination settings you require, is also a welcome feature.

Another cool addition of the Omega 8000 is the Pinpoint mode. If you sweep over an area and hear a beep, turning 90 degrees and sweeping again will allow the detector to accurately find the item and mark it with a cross, vastly reducing your digging time. Overall the detector looks cool, has a number of excellent features, is easy to put together and the digital display is extremely useful, although it would be even more attractive if the package came with some headphones.

Verdict:

2 Garrett Sea Hunter Mark II

Price: £549.95/$749.95
Get it from: metaldetectorshop.co.uk / garrett.com
A lot of metal detectors claim they can work in water or wet sand, but their accuracy varies wildly. The pulse induction technology in the Sea Hunter recognises the difference between saltwater and metal, something many other detectors are unable to do, therefore allowing you to search underwater for hidden treasure without constantly being sent down false paths.

The Garrett Sea Hunter MKII has two functions, the standard Trash Eliminator, which works as you'd imagine, and the Discrete Trash Eliminator, which has a much sharper reaction gradient, meaning at level two of eight it will pick up nickel and upward, as opposed to the standard level, which will steadily pick up all metal with less conductivity than that.

It's simple to put together within ten minutes, and the knobs are all very intuitive. However, when tested, no matter how much the various dials were turned (barring volume) there was little discernible difference, even when the iron tent peg that it had alerted us to was on the surface of the beach.

The Garrett Sea Hunter MKII looks stylish and picked up a variety of objects, but on a slightly damp beach, we found the discretion wasn't the greatest.

Verdict:

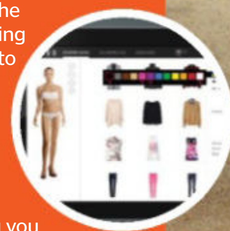
ON THE HORIZON

Some more cool tech that we would love to test out…

Wooden LCD watch

This attractive timepiece from Kisai is made of natural wood and contains a microSD card that can be transferred between watch and computer, saving you the hassle of carrying a USB stick around.

Fashion3D Virtual Changing Room



Designed to avoid the frustration of ordering clothes online only to find they don't fit. A Kinect camera places images of the clothes over your body, resizes them to find the perfect fit, allowing you to see what clothes look like before ordering on the web.

Eye tracker

Eye Tribe has carved a path in affordable eye tracking technology. Simply plug the tracker in to your computer via the USB port and it will follow your eye movements across the screen. This allows you to scroll through documents, pause TV shows and even play games using only your peepers. After selling out its first run, the next batch of Eye Tribe trackers should be out soon – keep your eye out at **theeyetribe.com**.

3 XP Deus

Price: £1,363/$N/A
Get it from: metaldetectorshop.co.uk

Another metal detector with an electronic display, the XP Deus is an incredibly powerful and precise piece of kit. It has ten different pre-programmed settings that are specially designed for a range of locations and targets, whether that's the beach, farmland or gold fields. The latter uses an All Metal Mode that searches deeper underground and doesn't reject areas that it usually would, because they contain coil-confusing minerals.

The discrimination settings are adjustable and the clear display informs you in an instant what metals you are rejecting. If you want a more lightweight option, then the display can be removed, but as this doesn't add on that much extra weight, we'd recommend keeping it on.

Another big plus with the Deus is that the headphones are wireless, so you won't get in a tangle like you can with the others and it gives you some much-needed freedom when sweeping the area.

The pre-programmed factory settings are very thorough and wide-ranging, but the XP Deus does allow for those who have more expertise to fiddle around with and save new settings, which makes this great for newbies and pros alike.

Verdict:

4 Minelab X-Terra 305

Price: £379.99/$399
Get it from: maplin.co.uk / amazon.com

The Minelab X-Terra 305 is a neat little machine, if slightly lacking in pleasing aesthetics. Easily put together, although the armrest was a little bit confusing, it is good to go within a few minutes. The large number of notches in the handle allows for treasure hunters of all ages and sizes to enjoy this machine, which is definitely a big point in its favour.

The two preset modes are ideal for beginners and in our opinion that is probably the main target market for this model. It doesn't have many bells and whistles, but it's simple to assemble, allows for instant searching and the large display is easy enough to read and decipher.

Like the Omega 8000, the X-Terra 305 comes with a series of tones to represent different metals and its lightweight design means that it can be used by the whole family, including the little ones.

You can opt for either medium-frequency (7.5kHz) or high-frequency (18.75kHz) coils with this detector, allowing for deeper and more accurate searching. The 305 is an excellent entry model and is also one that you could use to work your way up to the more illustrious brands.

Verdict:

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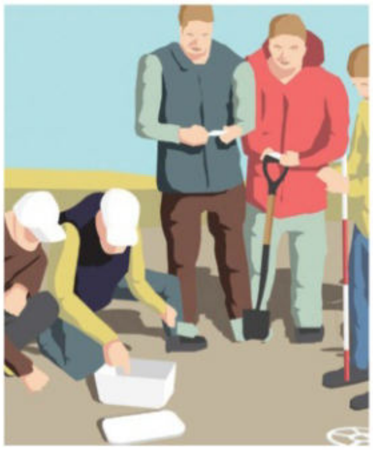
Hunt for treasure

Buried treasure is all around us, but how can metal detectors help us unearth it?



1 Join the club

Metal detectors cost anywhere from £35 to £500 ($60 to $830). The price difference is generally based upon its ability to differentiate between precious and worthless metals. Some metal detectors are able to operate in shallow water, which can provide richer pickings than dry land. There are also many clubs you can join, which is a great way of learning tips from seasoned pros, as well as making the activity more sociable.

2 Pick a good spot

You will often find people using metal detectors on a beach because that's where money and jewellery get dropped and buried or washed up from the sea. Alternatively, you could do some research and hunt in known historical sites, such as around hill forts and castles. These are prime locations for finding artefacts like ancient coins, weapons and farming tools, but you will need to be prepared to get a bit muddy.

3 Get permission

Before you even switch your metal detector on, make sure you are allowed to hunt in that spot. Searching on private land requires permission from the landowner. It may come as a surprise but even public beaches need a permit from the Crown Estate. While accessible to the public for general use, some coastlines are protected for historical or environmental value, so check you are allowed to hunt in a certain area beforehand.

4 Check your discrimination

The discrimination is the range of metals that your machine is set to pick up. Higher levels of discrimination will only find precious metals, while lower levels will alert you to lower-value metals like aluminium. One thing to note is that Roman and Celtic coins fall under lower-discrimination levels as they are made of metals like nickel, but are still fantastic finds – not to mention valuable.

5 Sweep motion

There's a special technique to using a metal detector, which basically involves walking slowly in a straight line and sweeping widely. Reach a predetermined point, move a metre or so to the side and start again. Overlap your previous sweep slightly in case you missed or disturbed something earlier. If you strike lucky, sweep that general area again in ever-expanding circles, because sometimes if one thing has been dropped in that area, more will be in the vicinity.

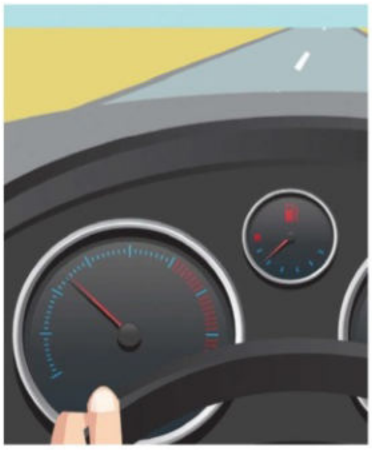
In summary...

The main aim of metal detecting is to find items of value, so try to make sure you have a quality detector as you don't want to be hunting all day only to build up a collection of foil or rusty cans. If you research your sites and sweep the area methodically, metal detecting can be extremely rewarding, besides getting you outdoors in the fresh air.

NEXT ISSUE
- Build a tree house
- Exercise in the office

Save on fuel

Petrol is a huge drain on a household's finances, so here are some top tips to make that tank last longer…



1 Smooth operator

The way you drive has a marked effect on your fuel consumption. Smooth driving without heavy acceleration or braking will maintain high efficiency. Part of this is planning your route and giving yourself as much time as possible to decelerate at a steady pace. Keep your car between 2,000 and 2,500 revs as much as you can, as running the engine at high revs burns through a lot of fuel.

2 Kill dead weight

Empty your car of anything you don't need. Open your windows at low speeds as air con adds up to seven per cent onto your fuel bill. At high speeds, the drag caused by open windows is significant enough to switch to air con. Making sure your tyres are fully inflated also makes your petrol go that bit further. Luckily, using the radio doesn't add to your petrol consumption, so feel free blast those tunes out!

3 Take the course

There are a number of specialist courses available for those wanting to learn how to drive really efficiently. Whether you're a professional or casual driver, shelling out a bit of cash for a driving course could help you save up to 30 per cent on your fuel bills, earning the fee back in no time. Not only that, but some claim you are also at lower risk of having an accident if you adopt a more efficient driving style.

In summary…

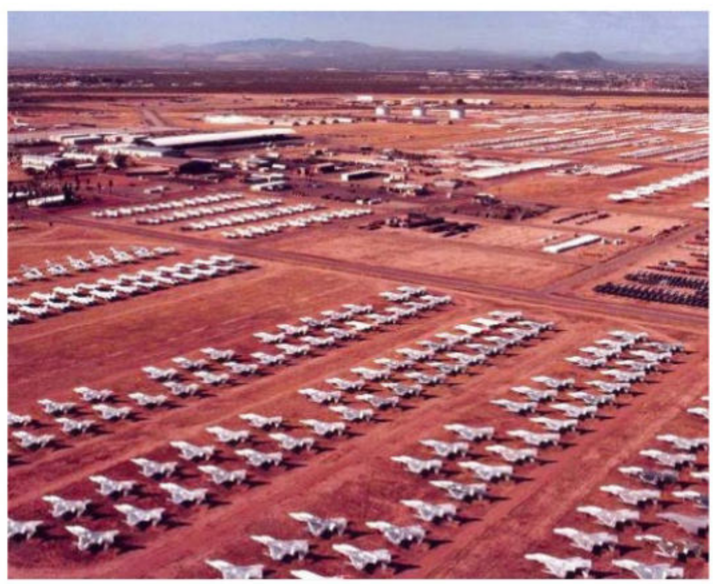
The idea of saving petrol is to save money and, in the long term, reduce the wear and tear of your car. Making tiny sacrifices in terms of speed, a bit of comfort and removing all unnecessary weight could save you a bundle of money so it's well worth re-evaluating how you drive.

QUICK QUIZ

Test your well-fed mind with ten questions based on this month's content and you could win a cool model of an Aston Martin DBR9!

Answer the questions below and then enter online at **www.howitworksdaily.com**

1. How many years ago did plants emerge from the water and take hold on land?
2. How many square kilometres is the biggest plane graveyard site?
3. What was the first rocket created at NASA's Vehicle Assembly Building?
4. Which virus causes chickenpox?
5. In what year did Max von Laue develop modern X-ray crystallography?
6. What is the minimum height of an effective chimney (in metres)?
7. At which battle was the Mary Rose sunk?
8. What is the man-made process to create ammonia called?
9. What nationality was the astronomer Nicolaus Copernicus?
10. Who greatly developed the field of forensic DNA profiling in 1984?



ISSUE 58 ANSWERS

1. Dolly **2.** 3,600km^2 **3.** Hippocrates **4.** Mitochondrion **5.** Boundary layer **6.** Menzel 3 **7.** Roman **8.** 1820s **9.** Jean **10.** 6

Get in touch

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WIN!

We enjoy reading your letters every month, so keep us entertained by sending in your questions and views on what you like or don't like about the mag. You may even bag an awesome prize for your efforts!

AMAZING PRIZE FOR NEXT ISSUE'S LETTER OF THE MONTH!

DISCOVER HOW THE DINOSAURS LIVED!

Next issue's Letter of the Month will win a copy of *The Paleoart Of Julius Csotonyi: Dinosaurs, Sabre-tooths And Beyond*. With over 150 pages of stunning prehistoric illustrations as well as Csotonyi's initial sketches, it's a must-have for dino and art fans alike.

Letter of the Month

3D printing heads up

Dear **HIW**,

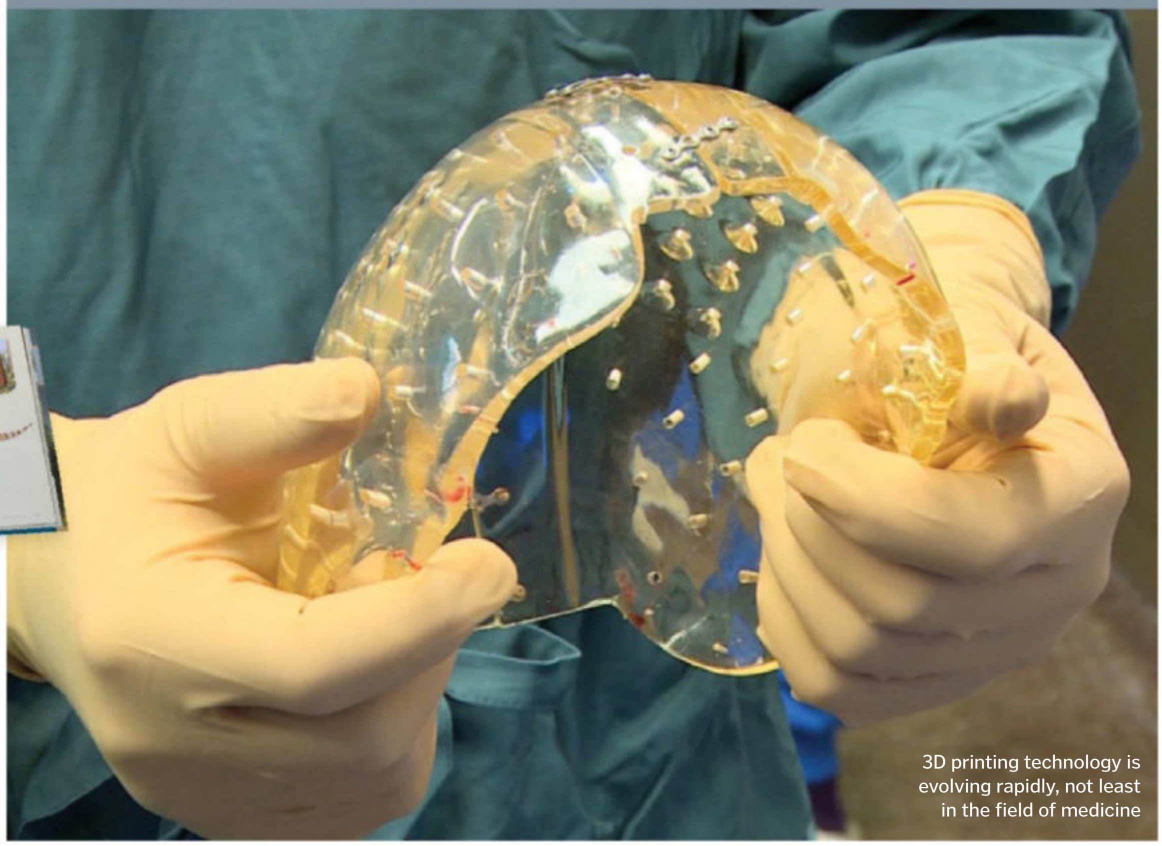
I fell behind recently in reading my magazine and am only just reading issue 57 on 3D printing. I noticed you give websites for 3D printing products and wondered if you know of a particular product I am trying to find.

I hope to one day have a career in biological anthropology and am thus a big fan of osteology. I've noticed lately that a lot of science presenters on television get 3D printouts of their own skulls, which is just amazing, and I have desperately been trying to scour the internet to find out where I can get my skull printed and how much it would cost, however I have had no luck. If you know a company from your research, please tell me.

PS your magazines are great to read.

Jessica

That's a cool career path, Jessica! As our cover story illustrated, 3D printing has truly arrived and all sorts of things are being made. Coincidently, in March the first-ever 3D-printed skull implant was carried out, where the top part of a 22-year-old woman's skull was replaced (pictured). For some boney inspiration, check out the website of Caspar Berger who reproduced a copy of his whole skeleton: www.casparberger.nl!



3D printing technology is evolving rapidly, not least in the field of medicine

Question of time

Hi **HIW**,

With respect to Einstein's theory of relativity, which states that the closer you get to the speed of light then time slows down, does that mean that time is losing energy?

Alasdair Macgregor

That's a very interesting question, Alasdair, if rather complex! Time is a dimension, a co-ordinate system we use to order events, not a physical entity. Therefore it is massless and has no energy.

The effect of time appearing to slow down is known as time dilation. At very high speeds, the passing of time varies, depending on the motion of the observer or the object.

If a clock is travelling through space close to the speed of light, it would appear to run slower than your Earthbound watch, but this is due to the time it takes light from the space clock to reach our eyes – you would effectively be comparing the current time on your watch to a past reading of the clock, so it appears to run slow.

Funnily enough, we are looking to include an article about the speed of light in an upcoming issue, so watch this space (and time)!

Quite quackers

Dear sir or madam,

This question has come to light after the start of the Sky programme, *Duck Quacks Don't Echo*. And of course, this is

Contrary to myth, duck quacks do in fact echo

“Time is a dimension, a co-ordinate system we use to order events, not a physical entity”

a lie. Duck quacks do echo. However, the question I will pose to you is: who first started this myth and why? And also, why did it continue?
Look forward to your reply,
Jake

You’re right, Jake, it is indeed a myth. From what we can gather, it is literally just an old wives’ tale that has caught on in popular culture.

While different species of duck might have different types of quack none of them have a sonic quality that prevents the call from echoing. You might find this absurd notion in all sorts of pub quiz trivia but never in a scientific journal.

Sky colour science

Dear Editor,
My name is Dylan Mills and I am 12 years old. I read issue 57 and I want to know: why is the sky blue? I hope you will reply with an answer.
Dylan Mills

Thanks for writing in, Dylan. Our world obtains virtually all its natural light from the Sun and this light is white. This white light is actually a mixture of all the colours of the rainbow, which can be seen if shone through a prism. When it travels to Earth it reacts with gases in the atmosphere, which means the light is scattered. The colour blue has the shortest wavelength of all visible colours so it is dispersed the most.

Also, have you noticed that when the Sun sets the sky turns red? This happens as the Sun is low in the sky, so light has farther to travel through the atmosphere and scatters more, so the longer wavelengths of red, orange and yellow reach our eyes. Hope you keep enjoying the mag!

Everyone has asked at one point or another why the sky is blue and it all comes down to light

What’s happening on... Twitter?

We love to hear from **How It Works’** dedicated followers. Here we pick a few tweets that caught our eye this month...

Chris @KRS_OVO
Best magazine ever! My subscription from #Europe finally started :-) #BrainFood

iansummers @iansums
What a great mag **@HowItWorksmag** why didn’t I have this when I was at school, life would have been so much easier!

Andrew Bentley @georgebentley22
@HowItWorksmag One of the best

XYZ @XYZBuilds
@HowItWorksmag excited to see what’s in store at the #toyzone for @GadgetShowLive 2014?

Jerry Chan @casual_twit
@HowItWorksmag
Love your magazine! Could there please be an article about how different musical instruments work? Or have I missed it?

JP Enterprises @JP_Enterprises
@AlfredoZuloaga this was interesting! Especially that our brains change objects to the colour it thinks they should be **@HowItWorksmag**

Cocktail Audio @cocktailaudio1
Guess who’s been awarded the **@HowItWorksmag** Editor’s Choice Award?

Ollie Iron @Ollie_Iron
Subscription issue arrived of **@HowItWorksmag** today... Have you guys done a ‘science behind cyberpunk’ article yet?

HOW IT WORKS

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